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Simulating Coarse-Scale Vegetation Dynamics Using the Columbia River Basin Succession Model—CRBSUM

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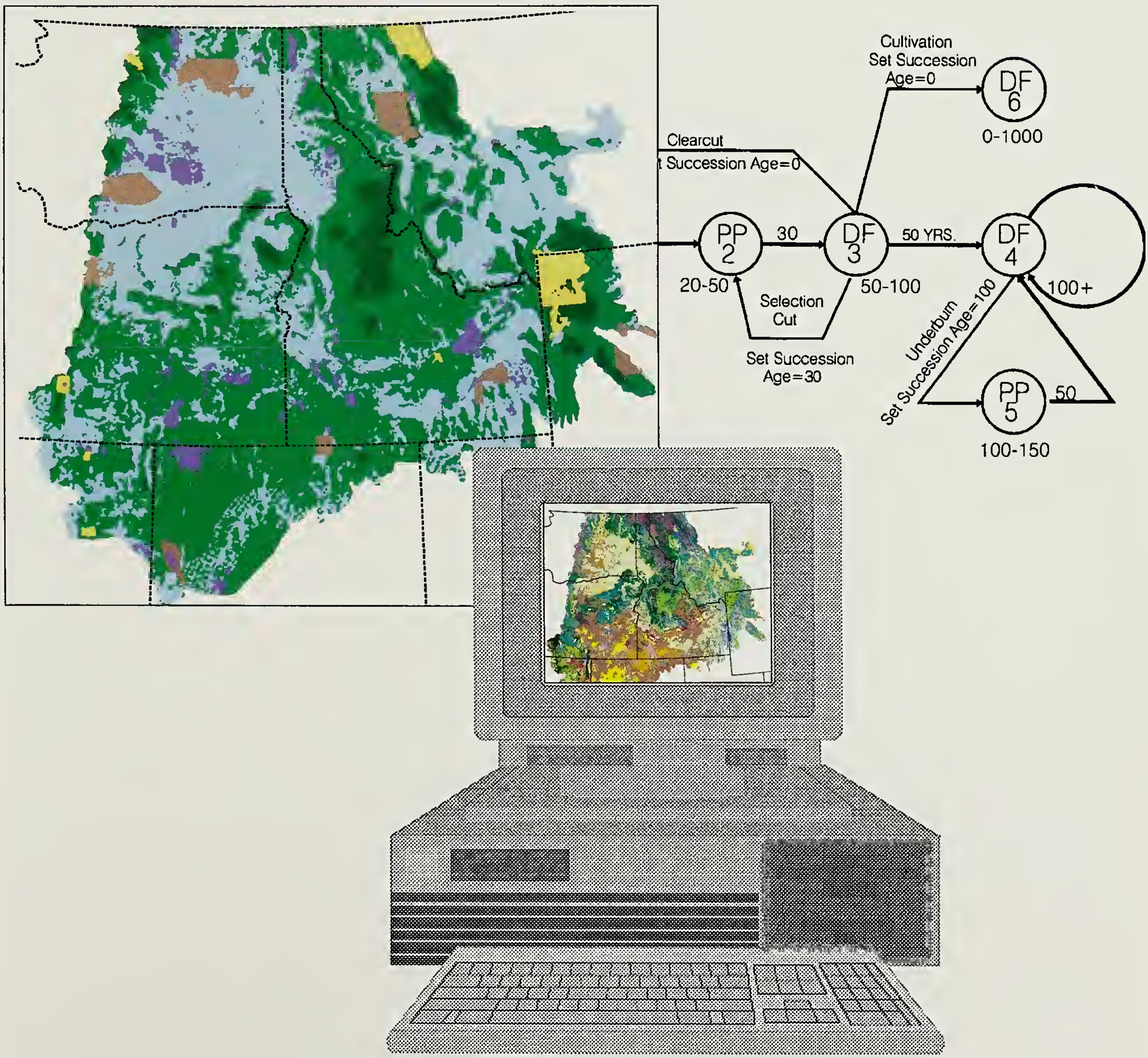

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Research Summary

The Columbia River Basin SUccession Model (CRBSUM) simulates broad-scale landscape changes as a consequence of various land management policies. CRBSUM is a coarse-scale, spatially explicit, deterministic model with stochastic properties that simulates changes in vegetation cover types and structural stages on large landscapes over long periods. It was designed to compare the effects of alternative management strategies on vegetation dynamics at a coarse spatial scale. CRBSUM is flexible and robust with all parameters and initial values specified as inputs to the model. Successional dynamics are modeled using a multiple pathway approach where successional community types, called succession classes, are linked along pathways converging to a stable community type called a Potential Vegetation Type. Each succession class is described by a cover type and structural stage. Disturbance is stochastically simulated as a change in cover type and/or structural stage using probabilities that reflect a possible management action or natural event. CRBSUM was used to simulate coarse-scale landscape changes in the Interior Columbia River Basin as a result of four management scenarios called management futures. Results from management futures that reflect current land management policies indicate cover types dominated by major seral tree species, such as ponderosa pine, western larch, and aspen,

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declined as much as 30 percent in 50 years. Historically, these same cover types were dominant on the Interior Columbia River Basin landscape. There were also major losses in fire-maintained structural stages under management futures with heavy fire suppression. CRBSUM results have an inherent 1 to 5 percent variability because of the stochastic structure of the model. Sensitivity analysis results suggest moderate changes in disturbance probabilities (25 percent increase) will only slightly affect simulated results.

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Introduction

As part of his plan for ecosystem management in the Pacific Northwest, President Clinton, in May 1993, directed the Forest Service, U.S. Department of Agriculture, to develop a scientifically sound, ecosystem-based strategy for the management of Federal lands in the Interior Columbia River Basin. The Chief of the Forest Service and the Director of the Bureau of Land Management further directed that a comprehensive ecosystem management framework and assessment be completed for all Forest Service and Bureau of Land Management lands in the Interior Columbia River Basin (fig. 1). This scientifically based appraisal, called the Interior Columbia River Basin Scientific Assessment project, was mostly completed by the spring of 1995.

The Interior Columbia River Basin assessment was simultaneously conducted at two spatial scales. The coarse-scale effort characterized ecological conditions for the entire basin at a resolution of 1 km^2 or map scale of about 1:250,000. The mid-scale effort described ecological conditions at a much finer resolution of 0.01 km^2 or map scale of 1:24,000 scale. The mid-scale assessment characterized landscape pattern and ecological process interactions using indices and metrics appropriate to the scale. However, the mid-scale assessment was performed only on representative watersheds (Hydrologic Unit Code 6th code, USGS 1991) that make up about 15 percent of the Interior Columbia River Basin.

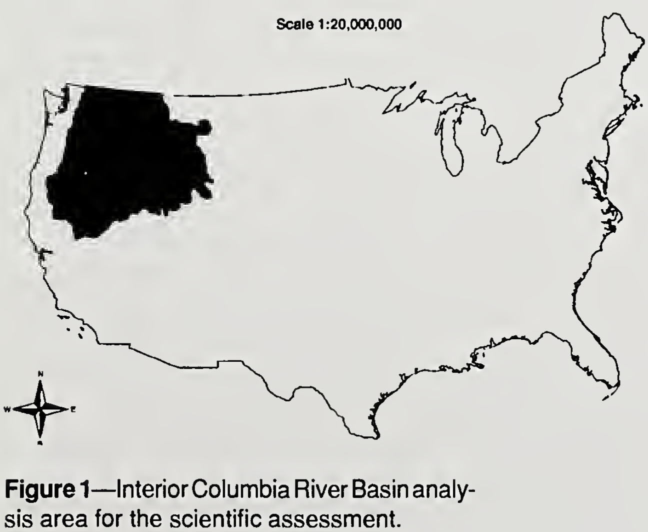


Figure 1—Interior Columbia River Basin analysis area for the scientific assessment.

This immense project (encompassing over 82 million ha) required the creation, compilation, and modification of a multitude of continuous, coarse-scale, spatial data layers for the entire basin to assess the area's natural resources and ecosystem processes. Moreover, many computer models were developed or modified specifically for the Scientific Assessment. These models allowed the comparison of the effects of alternative management actions on the composition, structure, and resources of future Interior Basin landscapes. The paper details the landscape succession model developed for the coarse-scale assessment called CRBSUM (Columbia River Basin SUccession Model) and presents some general results of the application of this model to the entire basin. CRBSUM was used to predict future landscape characteristics to evaluate management alternatives for both mid- and coarse-scale efforts. A test and sensitivity analysis of CRBSUM is also presented. This paper was written as a users guide for those who wish to run the model and interpret results, and it was also written as documentation for some results of the Interior Columbia River Basin simulation effort.

Model Overview

The CRBSUM computer program is a spatially explicit, deterministic vegetation simulation model with stochastic properties. Successional development on a

pixel (small portion of the landscape) is modeled as a change in structural stage and cover type keyed to successional time at an annual time step. Occurrences of human-caused and natural disturbances are stochastically simulated at a pixel-level from probabilities that describe a land use policy or management plan. Disturbance effects are deterministically simulated as an immediate change in structural stage and/or cover type with a corresponding adjustment of the successional clock. Initial succession age conditions for each pixel are stochastically assigned from input information for the potential vegetation type, structural stage, and cover type of that pixel. CRBSUM is a computer program developed in the C programming language for a SUN workstation and the UNIX operating system. This program is integrated with a collection of other C programs using the Loki simulation system. Loki is a simulation environment that allows the linkages of various computer models and databases in time and space. Output from CRBSUM can be imported into Geographical Information Systems (GIS) and databases for further analysis and display.

Background

One of the findings from the Eastside Forest project of 1993 was that succession modeling is critical for evaluating future ecosystem and landscape trends (Jensen and Bourgeron 1993; Kaufmann and others 1994). The Interior Columbia River Basin simulation effort specified several technical criteria for the design and development of the vegetation dynamics model that would be used to simulate landscape change:

1. **Spatial implementation**. The model must be implemented in a spatial environment and linked to a GIS. This meant that successional simulations needed to be geographically tied to the basin landscape. Simulation results must be mapped onto the landscape.
2. **Flexible**. Model design must allow for future program modifications and analysis options with minimal reprogramming. The model will be used for coarse-scale or mid-scale applications so input parameters must be external to the program.
3. **Wide scope**. The model must simulate succession for all lands within the Interior Columbia River Basin (in other words, continuous or wall-to-wall coverage). This includes all vegetation types (grasslands, shrublands, woodlands, forests, alpine, and rocklands) and all land use classes (agriculture, mining, human settlement). The model must simulate the consequences of all major disturbances on landscape (such as fire, harvest, grazing, population growth, insects, and disease) using a consistent framework.
4. **Simple**. This model must be easy to understand and use. Many diverse analysis teams with limited training will use the model and interpret the results.
5. **Team approach**. Model design must allow interactive integration of the cumulative knowledge of successional processes from many Interior Columbia River Basin natural resource professionals and researchers.
6. **Scale independent**. The model must be designed to use at many spatial scales, specifically, the mid-scale and coarse-scale.
7. **Time**. The model must be developed, tested, and operational within 8 months from the start of the effort.

These specific criteria prevented the use of many existing mechanistic, deterministic, and statistical models for Interior Columbia River Basin simulations. Modification and parameterization of mechanistic models such as FOREST-BGC (Running and Coughlan 1988), FIRE-BGC (Keane and others 1996), and gap-phase models (Botkin and others 1972; Keane and others 1989; Shugart and West 1980) were too costly and time-intensive, and the spatial scale and output were often inappropriate to evaluate Interior Columbia River Basin management alternatives. Statistical models such as PROGNOSIS or FVS (Wykoff and others 1982) were limited to only forested environments and were sometimes difficult to parameterize for all disturbances. Detailed stochastic models required quantification of probability distributions that were often scale or vegetation type dependent. It was decided that a flexible, robust, and simple model be developed specifically for the Interior Columbia River Basin effort and also for future ecosystem management projects.

Model Foundation—The framework of CRBSUM is a variation of a conceptual fire succession modeling approach introduced by Kessell and Fischer (1981). This diagrammatic approach is, in turn, based on successional modeling strategies developed by Noble and Slatyer (1977) and improved upon by Cattelino and others (1979). Many authors have since expanded Kessell and Fischer's (1981) approach to predict fire succession by potential vegetation types for many Northern Rocky Mountain forests (Bradley and others 1992; Crane and Fischer 1986; Davis and others 1980; Fischer and Bradley 1987; Fischer and Clayton 1983). Arno and others (1985) used a modification of this model to develop a successional classification of plant communities in western Montana. Keane (1987) created a computer model from this successional classification based on the multiple pathway logic.

Kessell and Fischer's (1981) approach links seral vegetation communities along multiple pathways of successional development (fig. 2). This approach assumes all pathways will eventually converge to a "stable" or "climax" plant community in the absence of disturbance. Fire disturbances will disrupt successional development and either delay the time spent in a community or cause an abrupt change in vegetation

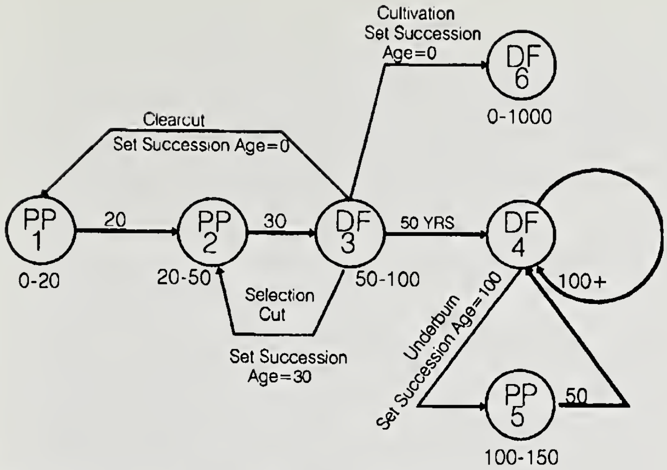


Figure 2—Hypothetical successional pathway for a Potential Vegetation Type (PVT). Numbers in circles identify the succession class.

community. The length of time spent in a succession class depends on the shade-tolerance and lifespans of the dominant species (Noble and Slatyer 1977). Hereafter, vegetation communities in CRBSUM will be called "succession classes" to minimize confusion between various approaches. This conceptual model has been expanded in the CRBSUM design to include disturbances other than fire and vegetation types other than forests.

Simulation Architecture—A computer software package called Loki, developed by Bevins and Andrews (1994), forms the simulation "platform" for CRBSUM succession modeling. Loki is a simulation environment that links various computer models and databases in time and space. It is an event-driven simulator that prompts execution of linked models according to events rather than time steps. Events can be disturbances such as a fire, or time intervals such as the conclusion of a year. In addition, Loki provides routines that access and modify spatial data layers. Other Loki routines allow the sharing of variables and files between programs. Loki serves as a "session manager" controlling the flow of program execution. Loki simulation software was integral in CRBSUM development (Bevins and others 1994). All input and output maps used by CRBSUM were assessed using Loki routines. Linkage of data summary and analysis programs with CRBSUM was also accomplished under the Loki architecture.

The Loki simulation software is valuable to ecosystem modeling because it allows cohesive integration of current ecological models (Shugart and West 1980; Urban and others 1991). Comprehensive simulation of ecosystem processes and their interactions is an extremely complex task, and the development of detailed mechanistic models to simulate these processes is often best left to the appropriate discipline. As a consequence, many of the same routines are reprogrammed for each major ecosystem modeling project. A software architecture that links various programs developed by experts would eliminate redundant program development and provide for more comprehensive applications.

A significant recent development in ecosystem modeling is the application of simulation models such as CRBSUM in a spatial domain, or landscape modeling. This involves dividing a geophysical setting (landscape) into a grid of square blocks called pixels. Each pixel has an attribute (such as a cover type code) that describes that corresponding piece of ground. The size of pixel relates to map resolution. A collection of pixel attributes in a complete grid is often called a raster layer. A raster layer can be included in a GIS if it is geographically referenced. The juxtaposition and adjacency of pixels both within and across raster layers are important characteristics in successional simulations. Furthermore, predicted maps of simulation results can be referenced to other raster layers such as ownership, climate, or topography.

Successional Modeling Fundamentals

Successional Pathways

Successional dynamics are modeled using the multiple pathway approach of Kessell and Fischer (1981) where succession classes are linked along pathways converging to a somewhat stable community type (fig. 3). There is a successional pathway diagram (set of pathways) (fig. 3) for each Potential Vegetation Type (PVT) implemented in the CRBSUM model. Many PVT's can be included in an application of the CRBSUM model. Figure 3 is a simplified successional pathway diagram for the Dry Douglas-fir PVT developed specifically for the Interior Columbia River Basin coarse-scale simulation during a series of workshops held in 1995. This pathway diagram will be used to illustrate many CRBSUM modeling concepts presented throughout this paper. Each box in this pathway identifies a succession class. The heavy arrows exiting out of a box denote successional development to the next class without disturbance. The amount of time (years) it takes to advance to another class is shown above the heavy arrows. The thin arrows identify the disturbance pathways taken when a class is perturbed. This diagram contains only disturbance arrows for harvest and grazing activities.

Potential Vegetation Types

A Potential Vegetation Type is based on the endpoint of the successional pathway diagram and identifies a biophysical setting that supports a unique and

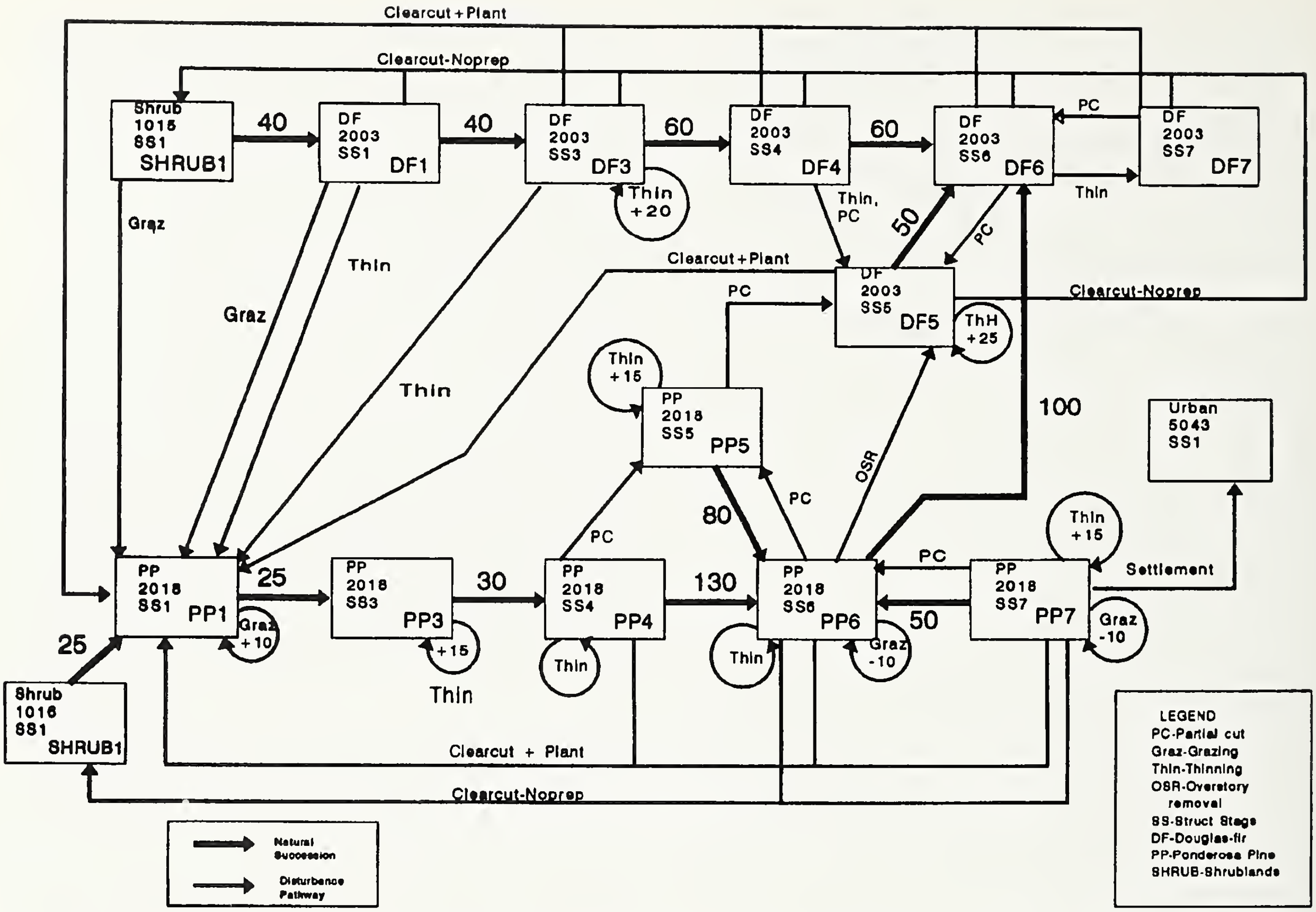


Figure 3—Succession pathway diagram for the Dry Douglas-fir Potential Vegetation Type. This diagram only includes timber harvest and grazing disturbance pathways. Four-digit numbers are numeric codes for cover types.

stable climax plant community (Arno and others 1985; Jensen and Bougeron 1993; Pfister and others 1977; Steele and Geier-Hayes 1989). Coarse-scale PVT's for the Interior Columbia River Basin were created by grouping similar habitat type and plant associations based on climate, topography, disturbance regimes, and geomorphology. This was accomplished through a series of seven workshops held throughout the basin in 1995. A list of the 55 PVT's used in the basin coarse-scale effort is presented in appendix A.

Succession Class

A succession class is described by a cover type and a structural stage (fig. 3). Cover types are named for the vascular plant species having the plurality of canopy cover for range types (Shiflet 1994) or for the tree species having the greatest basal area for forest types (Eyre 1980). The list of cover types used in the Interior Columbia River Basin effort is presented in appendix B. Cover type is depicted twice in each box in figure 3; the two-letter alpha-code in the upper left corner of each box (DF for Douglas-fir or PP for ponderosa pine) and a corresponding four-digit number (2018 is PP and 2003 is DF, appendix B) beneath the two-letter code.

Structural stages represent the developmental changes in a plant community's structure (Oliver and Larson 1990). Oliver's (1981) original structural stages were modified by O'Hara and others (1996) to account for the influence of natural and anthropomorphic disturbances on successional development in forest and woodland types. Willard and Villnow (1996) developed a set of structural stages for rangelands that were later revised for use in a coarse-scale application. Appendix C contains the list of structural stages by biome used in the coarse-scale effort. Structural stages are shown in the boxes of figure 3 as the concatenation of the letters "SS" and a number representing the stage (for example, SS4 is structural stage 4: understory reinitiation, appendix C). The succession class name is shown in the bottom right of each box as the concatenated cover type code and structural stage number (for example, PP4 is a Ponderosa Pine cover type, Understory Reinitiation structural stage).

Succession Age

The driving variable affecting successional change in CRBSUM is time measured in years. However, to link time to the successional development process requires the introduction of an abstract representation of time called succession age. Succession age is an index with units of years that is used to assess the degree of successional development of a class. This concept of succession age is different from stand age, which is the time since the last major perturbation. Stand age does not provide reference to changes in seral status because it is only relative to the last stand-replacing event. Successional development is not always linear with respect to time, and disturbances are not always stand-replacing. Succession age provides a measure to assess successional development along a successional pathway as a consequence of minor and major perturbations.

Succession age provides the option of setting the successional clock back to an age within a previous successional class rather than setting age to zero. This is especially useful when simulating perturbations that are not stand-replacement (such as thinning, wind-throw, overstory removal). An example of this is provided in figure 3 where a partial cut harvest (PC in fig. 3) of a pixel in succession class PP4 causes a change to succession class PP5. However, because this cut causes only minor changes in stand structure, the succession age is set to 105 years (from the calculation 25 + 30 + 130 – 80) which is approximately 50 years into the development of succession class PP6.

Disturbance

Ecological perturbations are modeled as an immediate change in succession age or succession class or, most often, both. Severe disturbances such as clear-cutting and stand-replacement fire will result in a succession class change to the earliest seral class in the pathway diagram, and the succession age will be reset to zero. Less severe disturbances (partial cutting or underburn) will cause minor changes in succession class and succession age. Some minor disturbances (such as thinning or disease infections) may cause an increase in succession age, accelerating the progress to the next class. For example, a thin in PP6 will increase succession age by 15 years (fig. 3). Other minor perturbations will decrease succession age, lengthening time spent in the class, such as grazing in PP6 decreases succession age by 10 years (fig. 3).

A few disturbances can cause a permanent conversion to a new succession class on a new pathway. For example, a pixel in PP7 succession class can be converted to an urban class because of human settlement (fig. 3). Other disturbances create new structural stages that eventually converge on the main succession pathway. For example, when a pixel in PP4 is underburned, it is converted to PP7 with succession age set at 100 years (not shown in fig. 3). However, after 50 years in PP7 without low intensity fires, the pixel reverts to PP6 (fig. 3). A partial list of common disturbances used in the Interior Columbia River Basin coarse-scale effort is shown in appendix D.

Model Design

CRBSUM is a spatially explicit, deterministic pathway model with stochastic disturbance functions that was designed to be flexible and robust. Parameters quantifying successional processes and input values describing disturbance regimes are not contained within the programming structure but instead are represented in files that are input to the program. This allows efficient modification of important succession parameters and the ability to perform simulation "gaming" with alternative scenarios without reprogramming or modifying the model.

The model's main structure is simply a rule-based decision module that (1) obtains a pixel's current PVT, structural stage, cover type, and succession age, (2) determines if the pixel is to be disturbed based on input probabilities, (3) decides the change in succession class if a disturbance is simulated, (4) computes any changes in successional development if there is no disturbance, (5) adjusts the succession age, (6) calculates and prints summary statistics, and (7) maps results. All decisions and evaluations made by CRBSUM are based on the data provided by the user in the input files. The linkage of input and output information is illustrated in figure 4.

Landscape changes are simulated as a change in the succession class (structural stage and cover type) of a pixel. A pixel's succession class can only be modified through management action, natural disturbance, or successional development (successional progress without disturbance). The sequence and longevity of succession classes are specific to a pixel's PVT and its corresponding successional pathway diagram. All parameters needed to quantify successional development pathways are entered into an ASCII file used as input to CRBSUM (fig. 4). This file, called the Succession File (example in appendix E), contains important succession information on the sequence of cover type and structural stage changes by PVT. This file is the heart of the CRBSUM succession model because it contains all parameters needed to simulate landscape changes over time. File records are entered hierarchically with disturbance data nested under succession classes which are nested under PVT's (appendix E). The Succession File is discussed in detail in the "Model Execution" section.

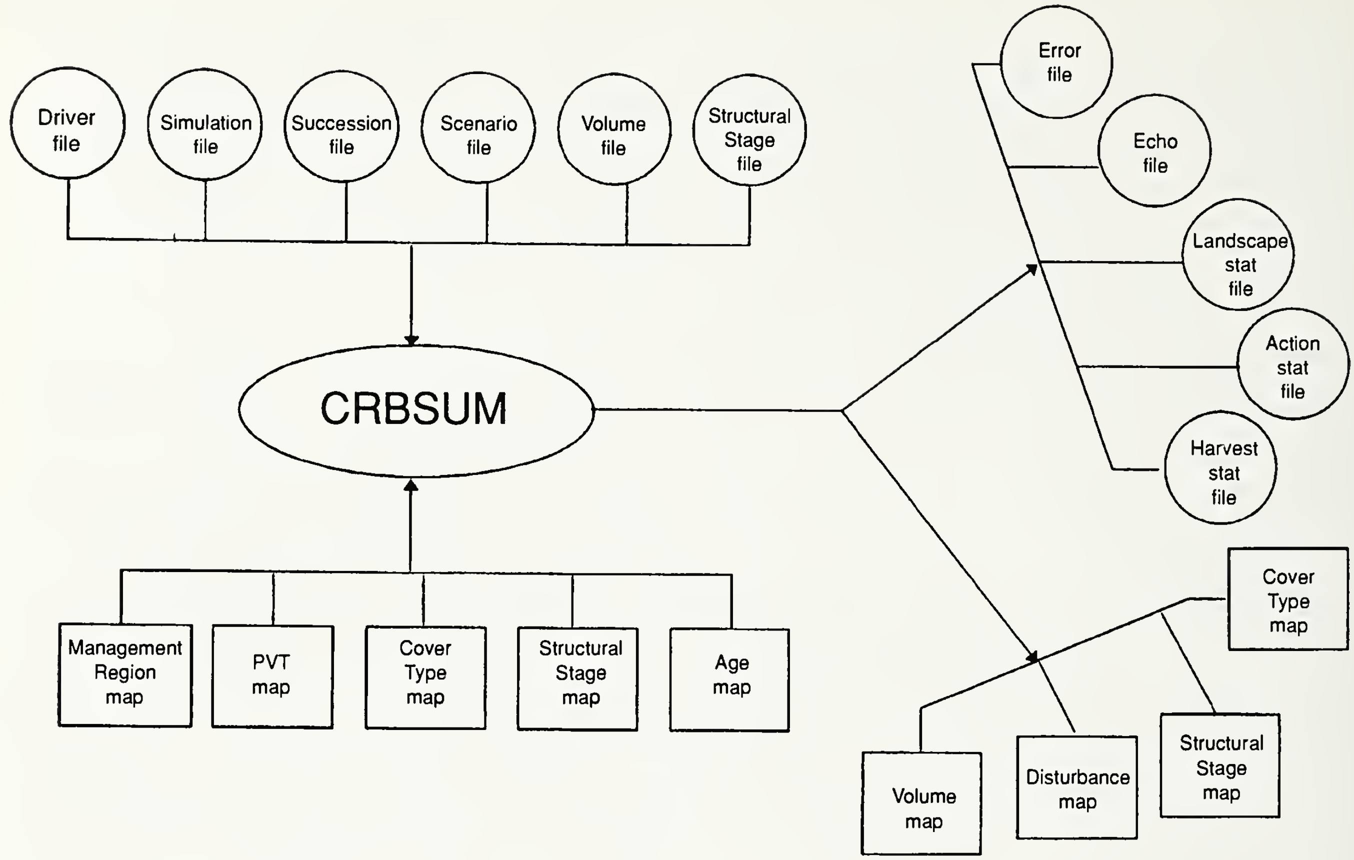


Figure 4—Information flow in CRBSUM. All major input and output files and maps are identified.

Disturbance Implementation

The incidence of a disturbance on the simulation landscape is simulated stochastically based on a user-defined management scenario. This management scenario contains the probabilities of occurrence for all possible disturbances that can occur for all PVT's and succession classes. These disturbances can be either human-caused or "natural" (that is, inherent disturbance characteristics of the ecosystem). Disturbances can cause a change in cover type, structural stage, or both, or they can cause a change in the succession age. Disturbance probabilities that compose a management scenario are entered in the CRBSUM input Scenario File (see appendix F).

Management scenarios are defined in CRBSUM as a set of probabilities that a pixel can experience as a particular management action or natural disturbance in any given year. These probabilities are stratified by geographical location, PVT, and succession class. For example, under a "Consumptive Demand" scenario, a pixel in northwest Montana having a Dry Douglas-fir PVT, stem exclusion structural stage, and ponderosa pine cover type might have a 0.001 probability of being clearcut and a 0.02 probability of experiencing a prescribed burn. These data are entered into the Scenario File (discussed in "Model Execution" section and an example in appendix F) (fig. 4). The set of disturbance probabilities by geographic region, PVT, and succession class is called a management scenario.

The user can implement disturbance probabilities for specific areas of land within the simulation landscape. These areas, called Management Regions, are spatially input into the model from a raster map. All management scenarios must be stratified by Management Region in the Scenario File. For example, fire and timber harvest probabilities will differ greatly based on management agency and land-use designation. So, disturbance probabilities in the Scenario File might be stratified by mappable land areas such as wilderness, Federal, and private lands.

The user also has the option of stratifying management scenarios and management regions by time intervals called Phases. For example, one management scenario might start at year 1 and go to year 10 when another set of management action or disturbance probabilities are used after year 10.

Spatial Implementation

CRBSUM uses the Loki map query routines to obtain pixel information needed to model succession across several raster maps. As yet, CRBSUM does not contain routines that incorporate the relationship of surrounding pixels into the simulation of disturbances. Therefore, successional development and disturbance effects are modeled pixel by pixel. However, a DISturbance CONTagion model (DISCONT) was programmed for application of CRBSUM at the mid-scale. Output of spatial results is accomplished using an ancillary program called ASCIIMAP linked to CRBSUM using Loki (Bevins and others 1994). ASCIIMAP creates spatial data layers for input to the ARC/INFO and GRASS GIS software systems (USA CERL 1990). Figure 5 illustrates the linkage of all programs in the CRBSUM Loki application.

Model Execution

Input File Structure

Six ASCII data files are used as input to CRBSUM: (1) Driver File, (2) Simulation File, (3) Succession File, (4) Scenario File, (5) Structural Stage Initiation File, and (6) Volume File (fig. 4). Data contained in these files are stored in memory at the beginning of a CRBSUM execution. The first file, the Driver File, is a metafile that contains the file names of all input and output files (appendix G). The Driver File name is specified on the command line used to initiate execution of the CRBSUM program. (See appendix H for an example of the Driver File.)

The Simulation File contains information on user-defined specifics of the simulation run such as the number of years to simulate, pixel size, and initialization values. Information on successional dynamics for all PVT's is contained in the Succession File (appendix E). Probabilities that make up a management scenario are entered in the Scenario File (appendix F). Data on the distribution of structural stages by PVT and cover types is contained in the Structural Stage Initiation File (appendix I). This file is used to initialize the CRBSUM Structural Stage Map if unavailable (see Input Maps in this section).

The Succession and Scenario ASCII files are structured hierarchically with finer stratifications nested within a coarse-scale framework. All information for a stratum is entered on one record (line) in the file. The level of stratification is usually indicated by the degree of indentation in the file. Data are entered on each file record in free format. Therefore, it is only critical that the information be entered in the correct order and be separated by at least one blank. An unfortunate "side-effect" of free-formatting is that alphanumeric names cannot contain blanks because the name-part after the blank will be interpreted as separate field and the program will return an error. So, another character should be substituted for the blank in two-word names (for example, use Whitebark-Pine or WhitebarkPine for Whitebark Pine). Alphanumeric names should be shorter than 64 characters. More than one space can be used to delimit fields so record information can be aligned by columns for ease of data entry and correction (see appendix E and F). The Identification Numbers (ID numbers) specified in each file must be consistent across and within files. For instance, if the Dry Douglas-fir PVT in the Succession File is assigned an ID number of 12, then the Dry Douglas-fir PVT in the Scenario File must also have an ID of 12.

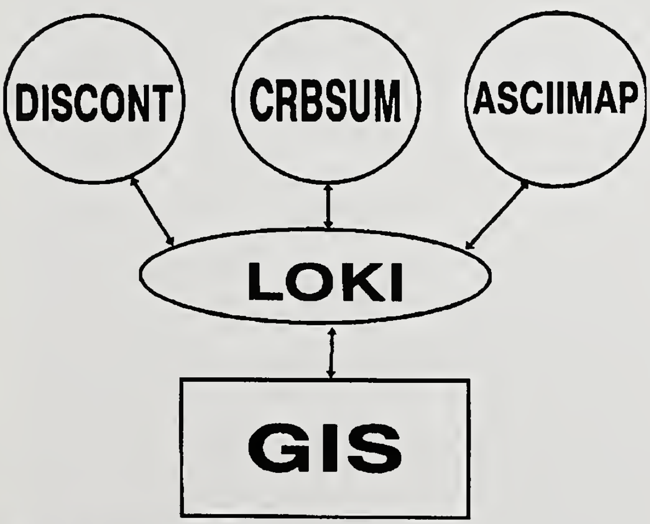


Figure 5—Programs used in the CRBSUM application of Loki.

Simulation File—The first line in the Simulation File is a title line used for file documentation and is skipped by CRBSUM (appendix G). This title line is present on all CRBSUM input files and is always skipped by CRBSUM. The remaining lines describe the specifications of a CRBSUM simulation (appendix G). Only one number is entered on each line. Number of years to simulate is entered on the first line. The second line is the date at which simulation is to commence. The scale of application is specified next. Mid-scale and fine-scale specifications require the linkage of the disturbance contagion model DISCONT to CRBSUM in the Loki application. The next few lines contain attributes that describe general characteristics of other input files. On the successive lines are entered the number of phases included in the Scenario File, number of Management Regions in the Scenario File, number of PVT's in the Succession File, and number of cover types in the Initial Structural Stage File. These numbers serve as error-checks on the data entered in the corresponding files.

The next set of lines specifies the options of the initialization and output routines. Structural stage initialization method is specified on the 10th line and succession age initialization option is entered on the 11th line (see Input Maps in this "Model Execution" section). Tabular output result format is specified on the next line where a full summary includes all types of output as discussed in Model Output of this section. A short summary creates a statistic file that describes only PVT/cover type/structural stage yearly distributions by Management Region; an action summary is a statistics file containing the extent of disturbances in the simulation area by PVT/succession class/management region; a full summary creates both files. The time interval (years) to report output is specified on the next line. Harvest volume output format is entered next with either volume estimates or volume codes specified. Harvest codes are used if no volume equations exist and the user wishes to compute volumes at a later date (see Volume Computation in this section).

The last set of lines identify the disturbances to plot on CRBSUM output maps. There is an output map for each of five broad disturbance categories: (1) Fire, (2) Insect and Disease, (3) Harvest, (4) Grazing, and (5) Generic Disturbance. Line 15 specifies the maximum number of actions to chart for each map. A number of disturbance ID's, up to the maximum specified on line 15, are specified on the next set of lines. These ID's identify the disturbances to be mapped as one entity on one output map. Disturbance type ID's are specified by the 4 digit action code (appendix D) entered in groups of 10 (maximum per line) for the next set of lines (appendix D). The name of the map is skipped by CRBSUM. The model plots the occurrence of these disturbances as a group and does not distinguish between codes for a given disturbance output map.

Succession File—The first line in the Succession File is also a title line used for file identification and is skipped by CRBSUM (appendix E). The next line contains general information on the first PVT, namely the PVT ID number, PVT name (without spaces or concatenated) and the number of succession classes associated with this PVT. The next line is indented and pertains to the first succession class of this PVT. Succession class records contain the succession class ID, structural stage ID, cover type ID, beginning successional year of the class, successional year marking the end of the class, succession class ID to use when succession age is greater than the ending year (that is, the next succession class in the pathway), initial succession age to use for the CRBSUM Initial Age Map (see Landscape Initialization in this "Model Execution" section), and number of disturbances that can affect this PVT/succession class combination.

The next set of lines contain information concerning disturbance effects on the succession class. These disturbance lines contain the disturbance ID, disturbance name, succession class ID that the pixel reverts to if this disturbance occurs, the succession age of the resultant class (called Age-Set field), and an age increment estimate (called Age-Increment field). These disturbance ages are discussed in detail in "Disturbance Simulation" section. The next line after the set of disturbance records contains information on the next succession class for this PVT, and succeeding that is the set of disturbances pertaining to that succession class, and so on. Each succession class need not have a full list of disturbances especially if a particular disturbance does not make sense, such as a tree selection cut in sagebrush grassland. However, each PVT in this file needs information on the entire set of successional classes in the pathway diagram. It is important that data in this file match corresponding data in the Scenario File discussed next. If the Scenario File specifies a treatment for a PVT/successional class combination that is not represented in the Succession File, the program will return an error and terminate.

Scenario File—This file contains the set of disturbance probabilities that represents a specific management scenario. The hierarchical structure of this file has these probabilities stratified by time interval (phases) at the highest level, followed by geographical area (management region) information (appendix F) next. These two levels allow the user to design scenarios for a variety of temporal and spatial constraints. Nested under the spatial stratification of disturbance probabilities are "landunits" that are a PVT/succession class combination treated as a single level in the Scenario File for simplicity, unlike the structure of the previous Succession File. Beneath the landunit level are the set of actions or disturbances that this PVT/succession class can experience in any given year.

The first record in the file contains data for the first phase of the scenario. The phase ID is entered first on the record, followed by the phase name, the year that the phase commences, the year the phase ends, and the number of geographic regions included in this phase implementation. Be sure the first phase starts with year zero and the ending year of the last phase matches the total simulation time (years). Geographical regional information is entered on the next record with region ID entered first, region name entered next, then number of landunits involved in the management action. Landunit information is entered on the next line with PVT ID number entered first, then the PVT name, the succession class ID number, and lastly, the number of possible disturbances involved at this level.

The next set of records detail the implementation of disturbances or management actions. The disturbance record format has disturbance ID entered first, then

disturbance name, and lastly, the probability that a pixel will experience this disturbance in any year. This probability can be viewed as the probability of any piece of ground (delineated by the square pixel) experiencing a particular perturbation that year within the specified phase and geographical boundaries for that PVT and succession class. The no-action management action is assumed by default so it need not be specified. For example, if a particular PVT/succession class combination is not entered in the Scenario File but occurs on the simulation landscape, then the pixels in this combination would only experience successional development as specified in the Succession File. Again, it is important that the specified disturbances for a landunit (PVT/succession class combination) are represented in the Succession File.

Structural Stage Initiation File—This file is a cross-reference table detailing the distribution of structural stages by PVT and cover type (see appendix I). It is only needed if there is NOT a raster map of initial structural stage conditions. This file is structured with structural stages nested under PVT and cover type at the coarsest level. This file need not be created for every CRBSUM application (see Landscape Initialization in this section).

The first line of this file contains information on the first cover type with the ID number first, followed by the cover type name and the number of PVT's that have this cover type in their pathways (appendix I). The next line has information on the first PVT where the first cover type might occur. The PVT ID, name and number of structural stages found in this cover type and PVT combination are then entered on this record in that order. This next set of records contains information on all structural stages that can occur in this PVT/cover type. The structural stage ID is entered first on the record followed by the name of the stage and the percent occurrence of this combination. The percent occurrence represents the relative frequency (in percent) of a structural stage in this cover type and PVT. These percentages must add to 100 across all structural stages within any PVT/cover type combination.

Volume File—A Volume File is needed if harvest volume estimations are to be computed and written to output files and to maps. This file contains volume equation parameters for each PVT, succession class, and harvest disturbance code (appendix D) combination entered in the Succession File. The volume equation is of the form:

$$V=\gamma\,(\alpha+\beta\,(T_t)) \qquad (1)$$

where V is timber volume (m^3), α is the volume (m^3) at the beginning of a succession class, β is slope of the line ($m^3\ yr^{-1}$), γ is a volume reduction factor to adjust for harvest technique, and T_t is the transition time to the next succession class in years (Stage and others, in preparation). An example of the file is shown in appendix J where the PVT ID is first, followed by the succession class ID, disturbance ID, unique map code ID (see Model Output in this section), the α coefficient, the β coefficient, and the γ coefficient. No volume estimates will be computed for PVT/succession class/Harvest combinations that do not have equations represented in the Volume File.

Input Maps

CRBSUM needs up to five maps to start simulation (fig. 4). These maps are imported to Loki from GIS software prior to CRBSUM execution (Bevins and Andrews 1994; USA CERL 1990). The first map is the Management Region Map (Loki map Mgtregion) that delineates those areas that will receive different sets of disturbance probabilities. CRBSUM uses the Management Region Map to define the effective simulation area and as input in the stratification of probabilities. All pixels having a zero in the Management Region Map will not be simulated. All other input maps with pixels having zero values where Management Region Map has values greater than zero are assumed to be in error. The second map is a raster layer delineating potential vegetation types and this map is called the PVT Map (Loki map Pvt). The third map is a raster layer of initial cover types (Initial Cover Type Map, Loki map Lcc). These three maps are required CRBSUM input layers.

Also needed for a CRBSUM simulation are the Initial Structural Stage Map (Loki map Stg) and Initial Succession Age Map (Loki map AgeInit) (fig. 4). These maps can either be created independently by the user or stochastically generated by the CRBSUM model during the dynamic initialization process. Methods of age and structural stage initialization are specified in the Simulation File (appendix G) and discussed next. The combination of PVT, cover type, and structural stage for any pixel will always key to a succession class, which along with PVT will reference all information in the Succession and Scenario Files.

Initial Structural Stage Map—There are four ways to initialize the structural stage map used at the start of a CRBSUM simulation. First, the user can create an Initial Structural Stage Map using the PVT and cover type raster layers, and the information contained in the Initial Structural Stage File (see Structural Stage Initiation File in this section). Structural stages are stochastically assigned to each pixel based on the probabilities of occurrence of the structural stages for a cover type and PVT combination taken from data contained in the file. These probabilities must be quantified from existing sources or databases.

The second and third methods involve creating the Initial Structural Stage Map from information in the Succession File. The second procedure assigns structural stage from PVT successional information by cycling through all succession classes in a PVT to find the first incidence where the succession class cover type matches the Initial Cover Type Map value for that pixel. The model then assigns the structural stage of that succession class to the pixel in the Initial Structural Stage Map. This approach is obviously biased toward the first occurrence of a cover type in the successional information data but provides a consistent means to assign structural stage across the entire landscape. The third option calculates the number of succession classes where the cover type from the Initial Cover Type Map matches the cover type in the succession class along a succession pathway for the PVT. Structural stage is then randomly selected from the matched succession classes using equal probabilities. This method has slower execution time but seems to more reasonably simulate initial landscape conditions.

The last method simply requires the user to create a starting structural stage layer independent of the CRBSUM modeling effort and import the raster layer to Loki. This option is the recommended method of structural stage initialization, and this is how the Interior Columbia River Basin simulation effort initialized structural stage data layers.

Initial Succession Age Map—The Initial Succession Age Map contains the starting succession age of each pixel. There are also four ways to create the Initial Age Map as specified in the Simulation File (appendix G). Starting succession age can be randomly chosen from the range of years spanning the life of the succession class for a pixel (see Succession File in this section). Second, the starting age can be assigned as the midpoint of this lifespan. Third, the initial succession age can be taken directly from the Succession File (see Succession File in this section) for a PVT/succession class combination (see appendix E). Lastly, the user can create an initial succession age layer apart from the CRBSUM model and import the raster layer into Loki. This last method is recommended but requires extensive data on succession age that may not be available in the CRBSUM context since most age data relates to stand age rather than succession age. The Interior Columbia River Basin simulation effort used the third method of age initialization.

Landscape Initialization

Error Scan—After the five initial map layers have been created and input into CRBSUM, the model performs an exhaustive data scan to ensure linkages between maps, Succession File, and Scenario File are complete. This involves confirming that the succession class, cover type, structural stage, and PVT values of each pixel are present in the Succession and Scenario Files. The program also checks successional pathway specifications and timespans for every PVT and ensures all are valid and possible. All parameters in the Scenario File are compared to those in the Succession File to confirm entered management actions for a PVT/succession class are represented in the successional information. All errors are printed to the Error File for viewing and reference (fig. 4). The name of this error file is specified in the Driver File (appendix H). The program will not proceed with the simulation until all errors are fixed. Minor warnings of parameter inconsistencies are also printed.

CRBSUM prints all input file information from the Simulation, Succession, and Scenario File to an ASCII output file (Echo File) as specified in the Driver File (appendix H) for user reference (fig. 4). This echo file is useful for locating sources of errors and for general input validation. Error messages printed in the Error File can be referenced to the Echo File to ensure the data were input into the model properly.

Dynamic Map Creation—The next task CRBSUM performs is the creation of several dynamic maps from information contained in the initial maps. A Cover Type Map (Loki map Cover) is copied from the Initial Cover Type Map (Loki map Lcc). The dynamic Structural Stage Map (Loki map Stage) is copied from the Initial Structural Stage Map (Loki map Stg) and Succession Age Map (Loki map Age) is created from the Initial Succession Age Map (Loki map AgeInit). This allows the preservation of initial conditions for subsequent CRBSUM runs.

Output Map Initialization—CRBSUM simulation results are written to a variety of Loki maps at the end of each simulation year (see Model Output in this section). All pixel values in these maps are set to zero at the beginning of a CRBSUM run. The only way to preserve the conditions in dynamic output file maps is to export the data to GIS compatible ASCII files using Loki routines and programs. The user must be careful not to start another CRBSUM run without saving output map information.

Model Simulation

Landscape simulation commences after input files are read into computer memory, maps are initialized, and spatial and file data are free of inconsistencies. The simulation procedure follows the program flow illustrated in figure 6. At the start of every simulation year, the model selects the first pixel in the northwest corner of the simulation landscape and obtains the pixel's management region, PVT, structural stage, cover type, and succession age from the appropriate

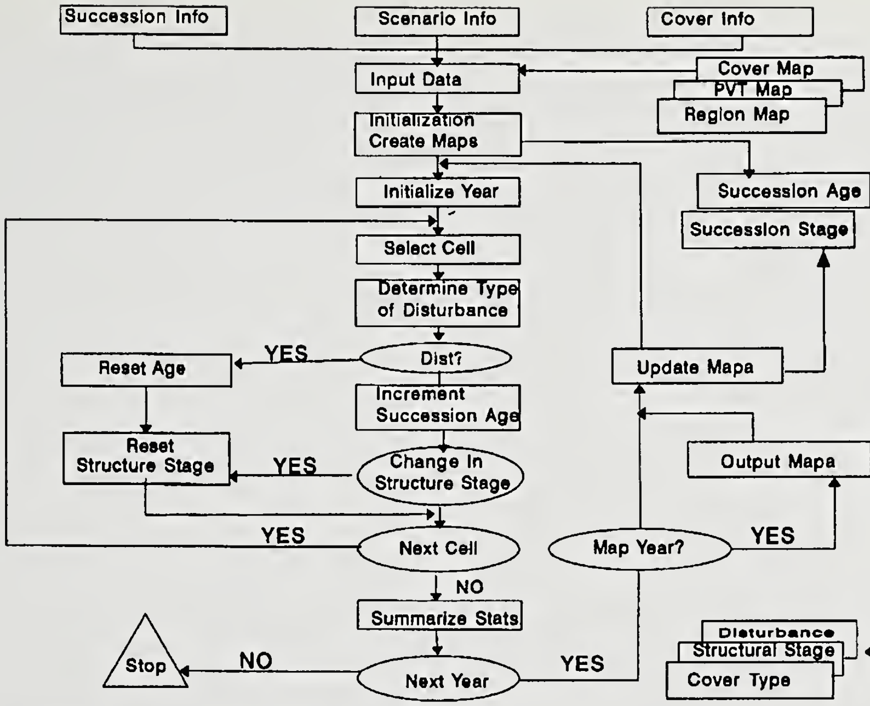


Figure 6—CRBSUM program flow diagram.

raster maps using Loki routines. CRBSUM will not simulate succession and disturbance on pixels where the management region value is zero. Next, the model keys to successional information and the list of actions this pixel can experience (see appendix E then appendix F) from the pixel's management region, PVT, cover type, and structural stage. Cover type and structural stage values reference a succession class in a PVT successional pathway.

Disturbance Simulation—CRBSUM creates a cumulative probability distribution from the entered disturbance probabilities in the Scenario File. This is done by summing all disturbance probabilities within a PVT/succession class. The model then generates a random number from a uniform random number distribution and compares it to the cumulative probability function. The disturbance whose bounds contains the random number is simulated. This is accomplished by taking the first disturbance probability and, if the random number is less than this probability, then that disturbance will be simulated. If the random number is greater than that probability, the next disturbance probability is added to the first and the same random number is compared to this new cumulative probability. If the random number is less than the summed probability, the second action is implemented. This process continues until all disturbance probabilities are summed. If no disturbance is selected from the list (that is, random number is greater than the total sum of all action probabilities), the pixel will only experience successional development and the succession age will be incremented by 1 year. However, if an action is selected, the pixel's structural stage, cover type, and succession age can be modified according to the parameters contained in the Succession File. Only one disturbance is simulated in a year.

This procedure is repeated for each pixel in the landscape that has a Management Region value greater than zero. Once all pixels are evaluated, the model outputs various maps, tables and files, and then simulates the next simulation year. All output data reflect conditions on the CRBSUM landscape at the end of the simulation year.

Successional Development—Successional development of a pixel is simulated by first adding 1 year to the current succession age. A change in succession class is simulated if the new succession age is greater than the ending year of the pixel's succession class as specified in the Succession File. If a change occurs, the model will assign that pixel the attributes of the new succession class which may mean a new cover type or structural stage or both. Successional progress is always forward in time and never retrogresses.

Disturbance Effects Simulation—If a disturbance occurs, the pixel's succession class is altered to the appropriate class specified in the Succession File. In addition, the succession age is set to the value entered in the Succession File. This new succession age can be less than the beginning age of the resultant succession class to prolong the length of time spent in the new

class. However, the new age can never be greater than the ending resultant class age. There are two ways in CRBSUM to alter succession age after a minor disturbance if the resultant succession class is the same as the current succession class (that is, disturbance did not change succession class). Each disturbance line in the Succession file has two resultant succession ages: the Age-Set and Age-Increment fields (see Succession File in this section and appendix E). CRBSUM looks at the Age-Increment estimate for the disturbance and, if this Age-Increment is zero, then CRBSUM will set the succession age to the age entered in the Age-Set field. The user ensures all disturbances affect the same result by entering zero in the Age-Increment field. However, if Age-Increment value is not zero, CRBSUM will add the Age-Increment value to the current succession age. The Age-Increment values can be either negative or positive. This algorithm allows the user to implement disturbances that can either accelerate (such as grazing) or retard (such as thinning) succession.

Volume Computation—The volume of wood (m^3) removed from a pixel by a harvest action can be computed by entering the desired option in the Simulation File (appendix G). These volumes are printed to the output Harvest File named in the Driver File (appendix H) and they are also mapped in the Loki Volume Map. Harvest volumes are computed using equation (1) and the parameters specified in the Volume File (appendix J). CRBSUM only prints volume estimates for those PVT/succession class/Harvest combinations specified in the Volume File. Only volumes from harvest activities specified in the Simulation File (appendix G) will be mapped onto the Volume Map.

Volume equation parameters are often difficult to quantify for all PVT's in a CRBSUM application. If no volume equations are available at the time of simulation, CRBSUM allows the user to output harvest actions by transition year in the Harvest Output File so volumes can be computed at a later time (option 3 on line 14 of Simulation File). CRBSUM will also map the occurrence of these harvests by recording a unique harvest code (appendix J) on the Volume Map. Additional resource values, other than timber volume, can be output in the future as algorithms and parameters are quantified and implemented into CRBSUM.

Model Output

Spatial Data Layers—CRBSUM prints simulation results to a variety of maps and files at the end of each simulation year (fig. 4). Cover type, structural stage, and succession age maps are updated each year. Programs can be added to the Loki system to export these maps to a GIS for examination and analysis (see ASCIIMAP in fig. 5). CRBSUM also updates the five disturbance Loki maps that contain distributions of disturbances simulated by the model. Wildland fire occurrences are provided in the FireOccurrence Map. Grazing, harvest, and insect/disease disturbances are written to the GrazeOccurrence, HarvestOccurrence, and BugOccurrence Loki Maps, respectively. A generic disturbance map called DisturbOccurrence allows the output of other types of perturbations such as windthrow, prescribed burning, and cultivation as specified in the Simulation File. The user has the option of storing any disturbance type on any map because maps are named for descriptive purposes only. For example, the user could output all wildfires to the FireOccurrence Map, all prescribed fires to the GrazeOccurrence Map, and all prescribed natural fires to the generic DisturbOccurrence Map. These maps can be exported from Loki into raster files with naming conventions that more accurately describe the file's contents and then imported into a GIS.

The types of disturbances recorded on these maps are specified in the Simulation File (appendix G). Codes specified in the Simulation File must match disturbance codes entered in the Succession File and action codes entered in the Scenario File. CRBSUM records the cumulative number of disturbances on each pixel in these maps up to the current simulation year. So, pixel values at the end of 100 years of simulation indicate the total number of disturbances for the entire simulation period. The disturbances are mapped as a group and not individually. Disturbance maps can also be exported to GIS by linking programs such as ASCIIMAP to Loki (fig. 5). These programs can export maps at long intervals, such as decades, instead of every year.

Volume estimates are stored in the Volume Loki Map. These estimates are summed across all years of simulation. The Volume Map can have two formats as specified in line 15 of the Simulation File. Volume estimates (m^3 wood) are written to the Volume Map if volume equations are specified in the Volume File and option 2 is specified on line 15 of the Simulation File. Past volume estimates are added to current simulated volume computations for each pixel and the sum is written to the Volume Map. Specification of option 3 on line 15 of the Simulation File will cause a unique, five-digit harvest code to be written to a pixel on the Volume Map every time a harvest is simulated. CRBSUM will concatenate up to three five-digit codes if other harvests are simulated for a pixel already having a five-digit code. Only volumes for those harvest disturbances specified for the HarvestOccurrence Map in the Simulation File will be recorded on the Volume Map.

Output Files—Four ASCII files are created by CRBSUM and updated each year. These files summarize simulation results for the entire simulation landscape. Output file selection is specified on line 12 in the

Simulation File (appendix G). The first file is a display file that summarizes CRBSUM output into a variety of formats. This file (CRBSUM.OUT in appendix H) presents summaries of number of square kilometers by cover type, structural stage, PVT, and so on. The next three files are printed in an ASCII format for use as input to various statistical programs (for example, S-Plus, SAS, SPSSX) or databases. The landscape summary file (LANDSCAPE.STAT) summarizes the annual area (km^2) distribution of cover type and structural stages by PVT and management region. The action file (ACTION.STAT) summarizes the area disturbed (km^2) each year by type of disturbance, structural stage, cover type, PVT, management region, and phase. Formats of these three files are described in detail in appendix K.

The last file (HARVEST.STAT) summarizes the area harvested by logging practices (km^2) each year by transition time to next succession class, harvest type, structural stage, cover type, PVT, management region, and phase. This file can have two formats as specified in the Simulation File. Volumes (m^3) harvested by PVT, succession class, and harvest code will be printed if there is a valid input Volume File (see Input File Structure in this section). Or, if there are no volume equations, then the user can specify that the area harvested (km^2) by transition time (decade), harvest code, succession class, and PVT be printed to the Harvest Output File. The Interior Columbia River Basin CRBSUM simulation effort computed harvest volumes from these data using a program developed by Stage and others (in preparation) that synthesized the results of thousands of runs of the Forest Vegetation Simulator (Wykoff and others 1982) model for many forest stands across the Interior Columbia River Basin. See appendix K for file formats and structures. This file can then be linked to volume equations at a later date with statistical software.

Interior Columbia River Basin Coarse-Scale Simulation Effort

The succession model CRBSUM was used to predict coarse-scale landscape vegetation changes for the entire Interior Columbia River Basin as a consequence of four management stategies. The primary objective of this simulation exercise was to contrast trends in landscape changes as a consequence of alternative land management policies over the entire Interior Columbia River Basin (fig. 1). These general land management policies were termed management futures for the Interior Columbia River Basin modeling effort. Four management futures were designed for the CRBSUM simulation to span the range of acceptable management strategies within the basin (table 1). A management future is designed by adjusting disturbance probabilities by PVT, succession class and management region to reflect a long-term land management goals. These futures bound the extremes of environmental impacts for any subsequent management alternative designed by environmental impact statement teams. A management future defines the limits of acceptability of a broad-scale, general land management strategy. A management alternative is a viable broad-scale Interior Columbia River Basin land use scheme tailored specifically for each management region.

Simulation Specifics

Several criteria were identified for the CRBSUM coarse-scale simulation runs. First, Interior Columbia River Basin landscape changes were simulated for 100 years using an annual time step. Second, maps of predicted cover types and structural stages were generated at simulation years 1, 10, 50, and 100. These benchmark years seemed to best capture trends over the ecologically important time intervals of years,

Table 1—General description of the four management futures simulated by CRBSUM for the scientific assessment modeling effort. These futures were designed by altering disturbance probabilities.

Name	Description	Code
Consumptive demand	Designed to meet social demands of consumptive use of all resources. Maximize harvests, roads, livestock grazing, mining, and include exotics.	CD
Historical	Designed to mimic pre-industrial historical, native American influences, and ecosystem processes. No exotics or livestock.	HI
Passive management	Designed to eliminate consumptive use of resources on Federal lands. No harvests, livestock, mining, hunting, and road-building. Assume same level fire protection as CD.	PM
Active management	Designed to mimic ecosystem function and restore various ecosystems. Harvests and prescribed fire are used to mimic ecosystem disturbance. Fire suppression is included.	AM

decades, half-centuries, and centuries. Cumulative occurrence maps of fire, insects and disease, grazing, and harvests were produced at these benchmark years. These maps portray the locations of the summed occurrences of a group of disturbances. Annual tabular summaries of predicted Interior Columbia River Basin landscape conditions were written to CRBSUM output ASCII files for input to statistical programs and database for subsequent summary. Volume estimates were computed for each simulated harvest and these estimates were mapped at the 1, 10, 50, and 100 simulation years on the Volume Map using the Stage and others (in preparation) equations and program. Harvests were also summarized by year in the CRBSUM Harvest Output File.

CRBSUM Input Maps

Many raster maps of biotic and abiotic attributes were created specifically for the Interior Columbia River Basin coarse-scale scientific assessment. Some of these layers were used to create input maps for CRBSUM. The following is a general description of CRBSUM input map development. A detailed discussion of the creation of these maps is presented in Keane and others (in preparation).

All initial CRBSUM input maps were created from base maps produced from other sources (Keane and others, in preparation). These base maps could not be used directly because the PVT, cover type, and structural stage for a pixel did not always match the succession pathway information. For example, a pixel might be a Dry Douglas-fir PVT on the PVT Base Map (Keane and others, in preparation; Reid and others 1995), but the same pixel might have a cedar/hemlock cover type on the Cover Type Base Map (Hardy and others, in preparation). The successional pathway diagram (fig. 3) has no cedar/hemlock cover type in a Dry Douglas-fir PVT. This inconsistency occurred on roughly 35 percent of the pixels in the Interior Columbia River Basin analysis area (fig. 1) and was mostly a result of a difference in mapping resolution and methods between the maps (Keane and others, in preparation). Most base maps ranged in scale from 1:250,000 to 1:1,000,000. Therefore, new cover type and structural stage maps had to be created for the CRBSUM simulation effort to match the PVT base map. The PVT base map was only altered when cover type information was known to be correct for a pixel based on ground truth data and available literature.

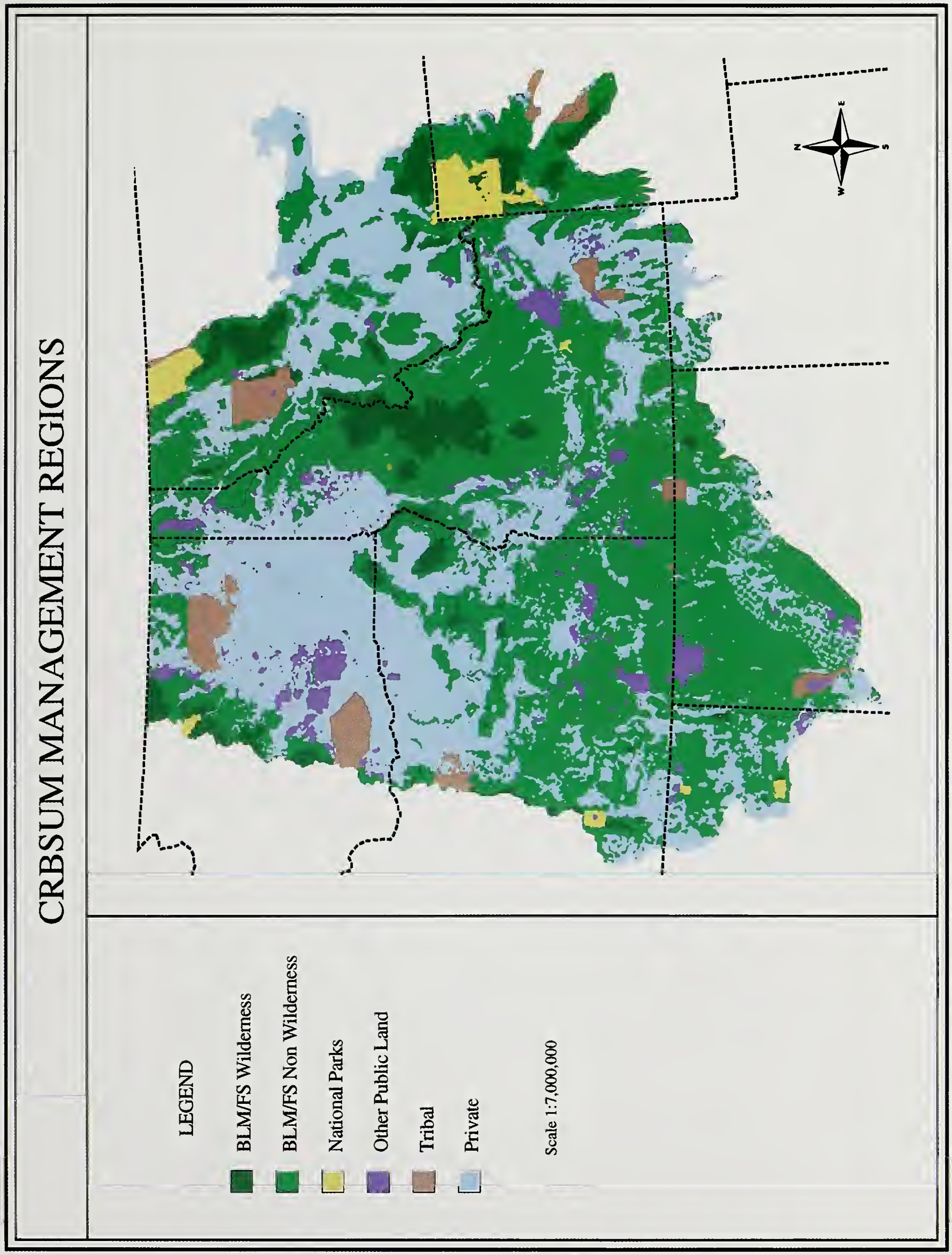
All base maps needed by CRBSUM were copied from original sources then modified to match succession class descriptions for the successional pathway as entered in the Succession File. For instance, the Cover Type Base Map developed by Hardy and others (in preparation) was copied and modified for CRBSUM simulation and called the "Current CRBSUM Cover Type Map." The input CRBSUM maps for three of the simulation scenarios (management future CD, AM, PM as defined in table 1) were initialized using the developed Current CRBSUM PVT and Current CRBSUM Cover Type and Structural Stage Maps. The historical management future simulation (HI in table 1) used the Historical CRBSUM PVT and Historical CRBSUM Cover Type and Structural Stage Maps. The following describes how each CRBSUM input map was created for the current management future simulations (CD, PM, AM) and the historical management future (HI) simulation run.

Management Region Map—The Management Region Map was created specifically for the Interior Columbia River Basin Scientific Assessment from a GIS ownership layer and a map of coarse-scale ecosystem boundaries (color plate 1). This map was used for both current and historical simulations. There were 18 management regions specified for CRBSUM simulation effort (described in appendix L and mapped in color plate 1). Approximately 822,000 one km^2 pixels, encompassing some 200 million acres, make up the CRBSUM simulation area for this effort (that is, pixels having a Management Region value greater than zero). The entire GIS layer was 1,122 rows by 1,222 columns, or approximately 1.3 million pixels including the zero values pixels.

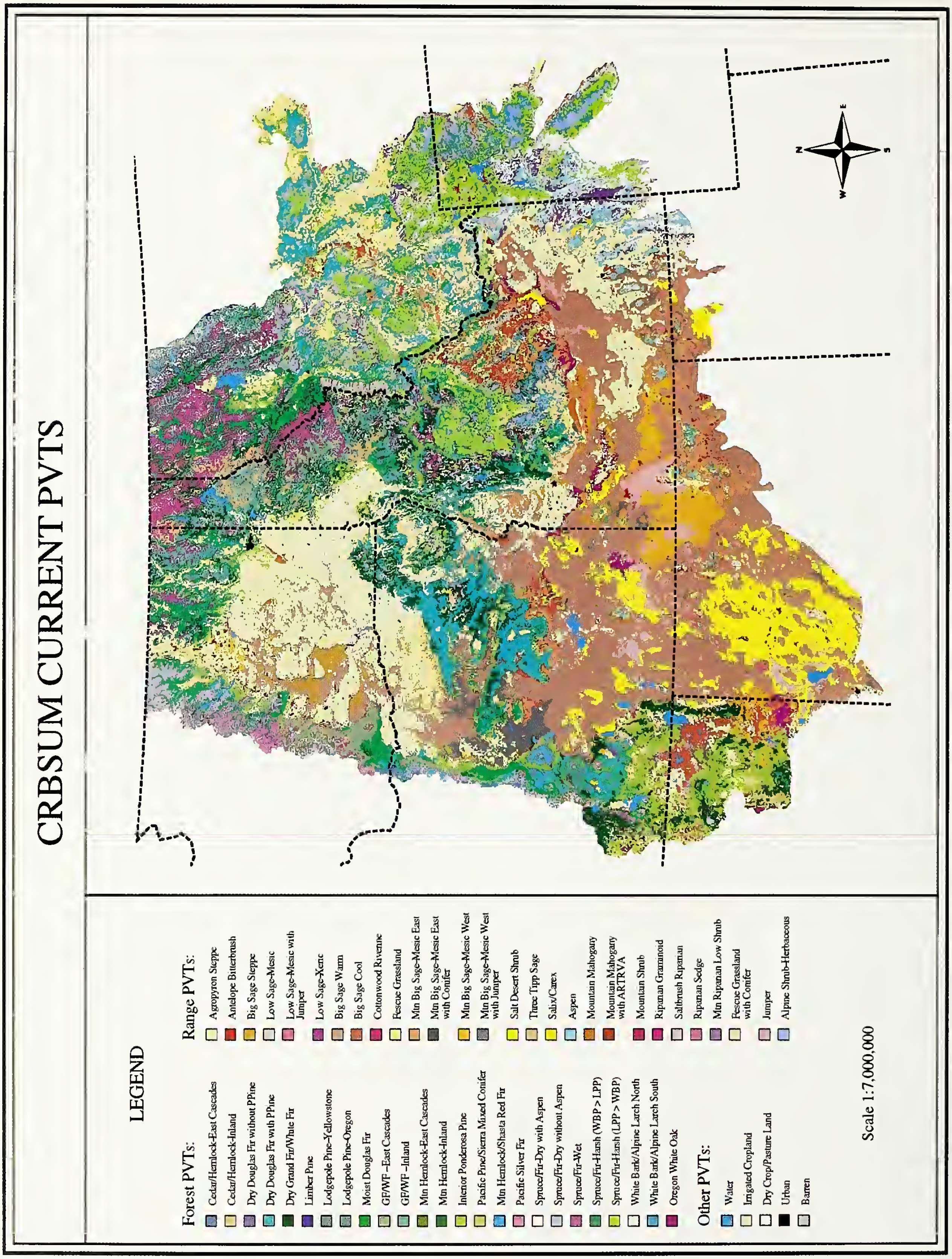
Current CRBSUM Simulation Input Maps—This set of CRBSUM input maps describes vegetation conditions as they exist today (circa 1990). The PVT Map (color plate 2) was based on a classification of biophysical settings created by a team of ecologists (Reid and others 1995). Biophysical settings were mapped using elevation, aspect, slope and soil characteristics by geographical region, climate, and geomorphological landform (Bougeron and others 1995; Reid and others 1995). Biophysical setting categories were cross-referenced with a list of Interior Columbia River Basin potential vegetation types for succession modeling. This list of PVT's was generated from a series of workshops attended by ecologists that quantified succession pathway diagrams for all PVT's across the entire Interior Columbia River Basin.

The Current CRBSUM Cover Type Map was created from a raster map of existing cover types compiled by Hardy and others (in preparation) (color plate 3). These researchers created their cover type base map by revising and refining a land cover characterization map that was constructed from a classification of temporally stratified AVHRR satellite imagery (Loveland and Ohlen 1993; Loveland and others 1991). This map was further refined using information gained from workshops attended by Basin ecologists (Hardy and others, in preparation).

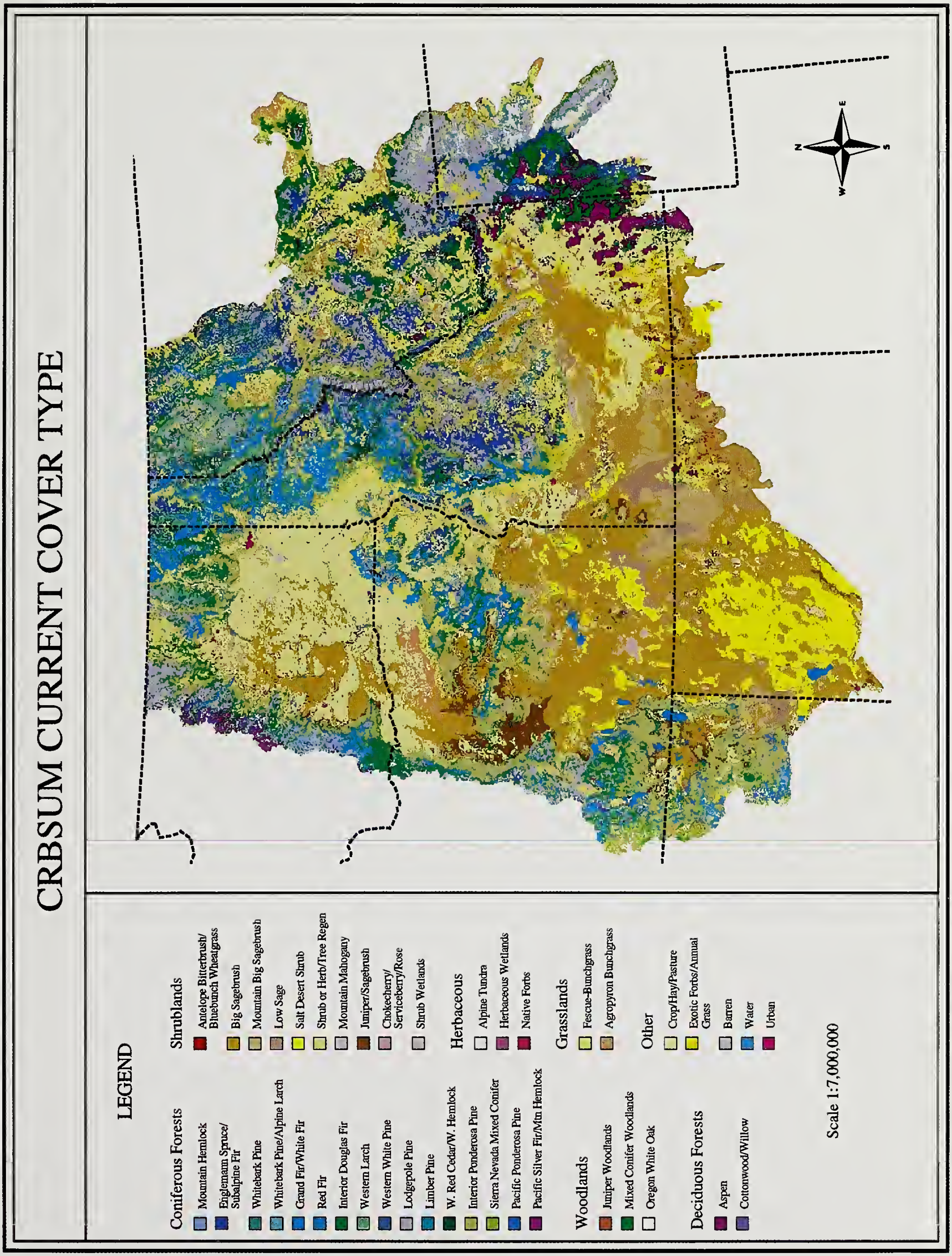
The Current CRBSUM Structural Stage Map (color plate 4) was created from a discriminant analysis of



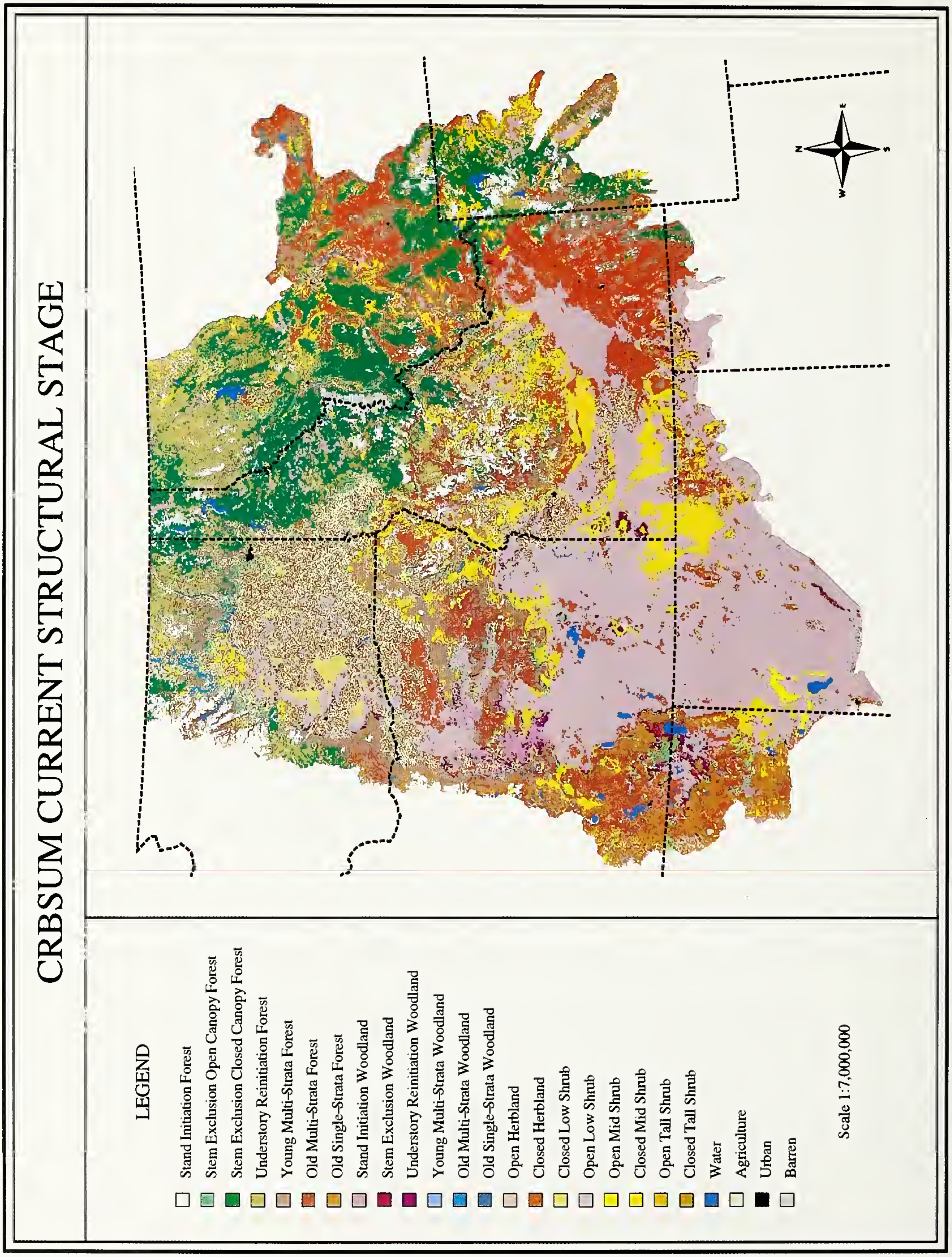
Color plate 1—Management Region map used in the CRBSUM modeling effort for Interior Columbia River Basin scientific assessment. The 18 management regions (appendix L) have been aggregated to six in this figure to reduce complexity and aid in visualization.



Color plate 2—Potential Vegetation Type map used in the CRBSUM modeling effort for Interior Columbia River Basin scientific assessment.



Color plate 3—The Current CRBSUM Cover Type map developed from the cover type base map of Hardy and others (1996).



Color plate 4—Current CRBSUM Structural Stage map used in the modeling effort for Interior Columbia River Basin scientific assessment.

mid-scale data layers extrapolated to the coarse-scale (Keane and others, in preparation) (see CRBSUM Structural Stage Maps discussed later in this section). The Initial Succession Age Map was computed within CRBSUM by randomly selecting a succession age from the life-span of a succession class. This simulated Initial Succession Age Map was used for all current management future simulations (CD, PM, AM) and another was simulated for the historical simulation (HI). Succession class was keyed from the PVT, cover type, and structural stage pixel values.

Historical CRBSUM Simulation Input Maps—The Historical CRBSUM Cover Type Map was produced by Losensky (1994) using archived maps and historical records published at or near the turn of the century. Because this map was compiled from many maps of varying scales and quality, it was difficult to match to the Current CRBSUM PVT layer and successional pathway information, especially for urban and agricultural areas. Consequently, a Historical CRBSUM PVT Map had to be created to account for PVT changes caused by land management practices in the last century. This was done by modifying the Current CRBSUM PVT Map to match the resolution and characteristics of the Historical CRBSUM Cover Type Map. The historical maps portray vegetation conditions that occurred around the beginning of this century (circa 1900).

CRBSUM Structural Stage Maps—Current and historical maps of Interior Columbia River Basin structural stages were created specifically for CRBSUM simulations without the use of existing base maps (Keane and others, in preparation). The Current CRBSUM Structural Stage Map was produced using multivariate discriminant analysis (Keane and others, in preparation) (color plate 4). Mid-scale structural stage data (100 meter pixel size) delineated from aerial photography were summarized to the coarse-scale (1,000 meter pixel size) by selecting the modal structural stage of all mid-scale pixels within each 1 km coarse-scale pixel. Each modal stage had to occur in at least 60 percent of the 100 m pixels within the 1 km pixel. A discriminant analysis was then performed using data from all 1 km pixels assigned a structural stage value from mid-scale data. The dependent variable structural stage for a pixel was predicted from independent variables taken from other coarse-scale Interior Columbia River Basin data layers for the same pixel. All biophysical and vegetation-based layers such as elevation, aspect, slope, and cover type, were included as independent variables in the discriminant analysis (Keane and others, in preparation). The resultant discriminant analysis function was then employed to predict structural stage for remaining Interior Columbia River Basin pixels using the same independent variable data layers. A separate discriminant analysis was performed for forest, rangeland, and woodland ecosystems.

The Historical CRBSUM Structural Stage Map was stochastically generated from historical information compiled by Losensky (1994) where the proportion of land area in each structural stage was reported by historic cover type, State, and county. This information was summarized to estimate structural stage percentages by cover type by Bailey's (1995) ecological divisions using GIS overlay techniques (Keane and others, in preparation). CRBSUM was then used to stochastically generate the structural stage of each pixel based on the percentages in historic cover type and ecological section.

CRBSUM Input Files

Succession File—Succession pathway parameters for all Interior Columbia River Basin PVT's were quantified from seven workshops held across the Interior Columbia River Basin during 1994 and 1995. These data were preliminarily estimated from raw data, publications, and professional "best guesses," then refined using a succession model similar to CRBSUM called the Vegetation Dynamics Development Tool (VDDT) (Beukema and Kurtz 1995). This tool uses the same algorithms as CRBSUM but does not have a spatially explicit application (Beukema and Kurtz 1995). In addition, only one PVT can be evaluated at a time in the VDDT program. However, the VDDT model is a dynamic diagnostic tool to quickly and efficiently improve succession pathway parameters and understand predictions. Refined succession parameters from VDDT were then imported into a PARADOX database for subsequent export to CRBSUM. The interim database storage allowed efficient global modification of some input parameters as additional knowledge was attained and new disturbances and pathways are added.

Scenario File—Management scenario probabilities were also quantified at the succession workshops for the four management futures—CD, HI, AM, and PM. The VDDT model was again used to refine disturbance probabilities by management region and management future (Beukema and Kurtz 1995). Finalized disturbance probabilities were again imported to the PARADOX database for later export to CRBSUM.

CRBSUM Sensitivity Test and Validation

A comprehensive analysis of CRBSUM parameters was performed to evaluate the importance, or sensitivity, of input parameters to simulation results. In addition, this analysis quantified the inherent variability of CRBSUM stochastic predictions so results can effectively be contrasted and interpreted. The Yakima Drainage Basin, a large watershed on the western edge of the Interior Columbia River Basin, was used for the CRBSUM sensitivity analysis (fig. 7).

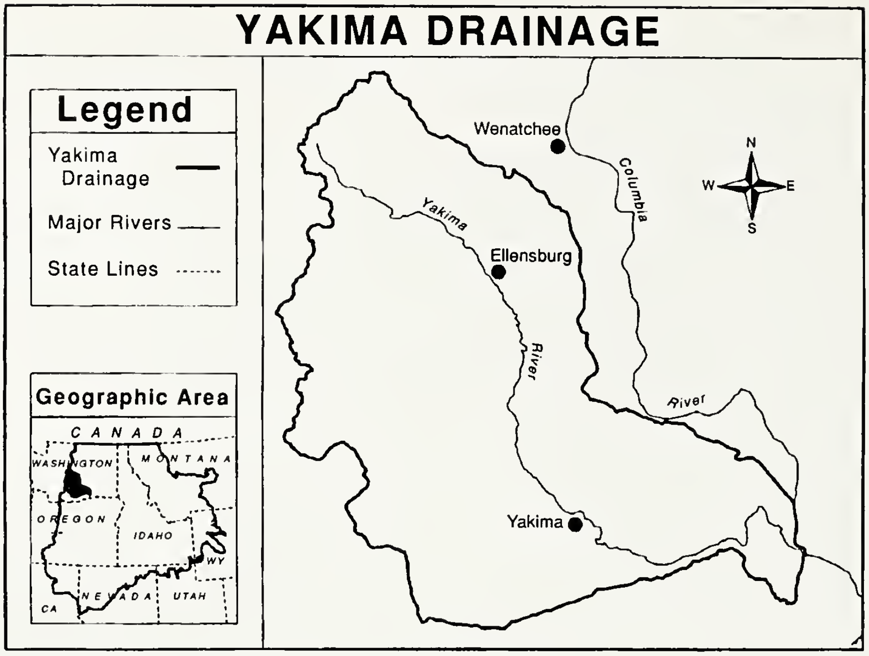


Figure 7—The Yakima Drainage Basin used for the CRBSUM sensitivity test.

This watershed is approximately 16,000 km^2 (1.9 percent of the Interior Columbia River Basin) and contains 13 Interior Columbia River Basin PVT's with rangelands dominant at the lower elevations; Douglas-fir and ponderosa pine forests common at the mid-elevations; and subalpine fir, spruce, and whitebark pine forests frequent in subalpine areas. This drainage basin was the prototype area used for initial tests of CRBSUM algorithms and execution during December of 1994. The entire Interior Columbia River Basin was not used in the sensitivity test because of the enormous size of each GIS layer (approximately 5 megabytes) and the long computation time needed to complete a simulation (30 to 50 hours).

Cover Type Prediction Variability—CRBSUM was run 100 times for 100 years each to estimate the range of variability in cover type predictions due to the stochastic nature of the model. The Consumptive Demand (CD) Scenario File was used in this effort. Land area projections for common and rare forest and range cover types were recorded at 1, 10, 50, and 100 year(s) for each of the CRBSUM simulations. The mean, variance, range, and coefficient of variation of the forest and non-forest cover type predictions were computed at the time intervals.

Disturbance Parameter Sensitivity—Probabilities for the stand-replacement fire, clearcut harvest, mountain pine beetle, and livestock grazing disturbances (appendix D) were increased by 25 percent, one at a time, for all instances in the CD Scenario File. These disturbances were selected because they are common on the Yakima Drainage, and their effects generally represent the effects of other disturbances. One of the four disturbance probabilities was globally altered in the Scenario File and this file was then used as input to CRBSUM for simulation of the Yakima Drainage. The change in cover type coverage over 100 years was contrasted with and without the 25 percent increase at each of the benchmark simulation years.

CRBSUM Accuracy Test—It is nearly impossible to validate predictions of a model with such a wide scope and coarse-scale application. However, one method evaluates the behavior of CRBSUM using "known" conditions. The historical CRBSUM input maps were used as input to CRBSUM and the model was executed for 100 years under the Consumptive Demand management future. The cover type map generated by CRBSUM at simulation year 100 was compared with the Current CRBSUM Cover Type Map and the Hardy and others (in preparation) Cover Type Base Map for reference. This comparison assumes that the Consumptive Demand (CD) management future best describes land management over the last century and the historical maps accurately represent vegetation conditions around the year 1890.

Interior Columbia River Basin CRBSUM Simulation Results

A comprehensive summary of all CRBSUM output generated for all management futures would not be

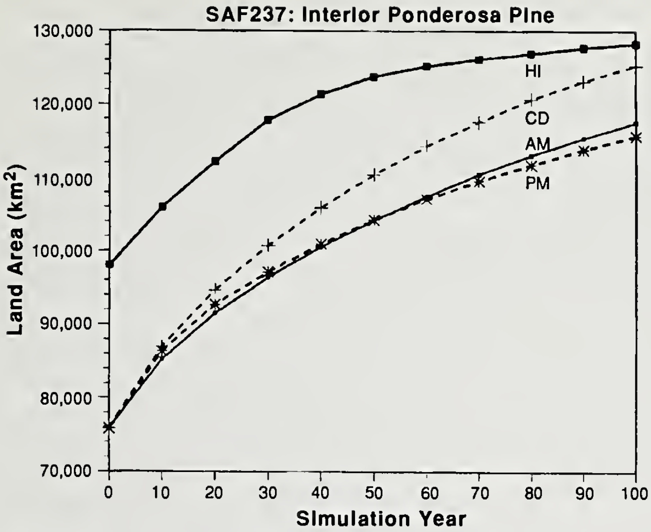


Figure 8a—Predicted land area (1,000 km^2) for ponderosa pine cover type across the entire Interior Columbia River Basin.

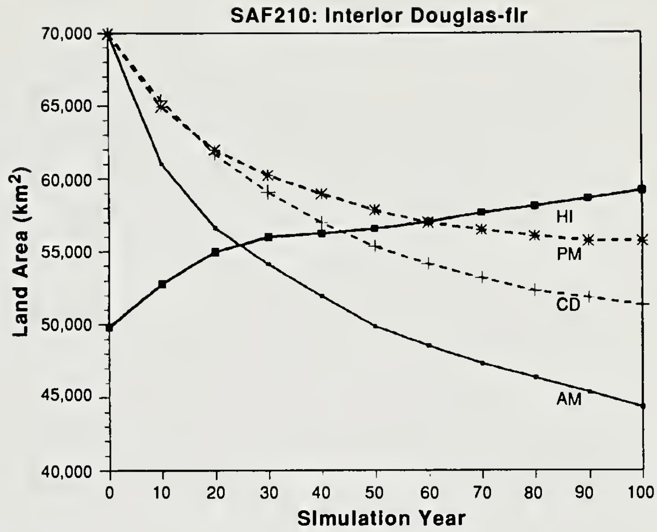


Figure 8b—Predicted land area (1,000 km^2) for Douglas-fir cover type across the entire Interior Columbia River Basin.

appropriate for this paper because of the shear immensity of the output data. CRBSUM produces about 90 megabytes of tabular data and 150 megabytes of map layers for each management future. There are some 7 output maps of about 5 megabytes in size for each year of output (1, 10, 50, 100) for each management future. The model takes about 30 to 50 hours to complete a 100-year Interior Columbia River Basin simulation run, depending on the complexity of the management future. Therefore, only general examples that show the breadth of CRBSUM predicted variables will be presented.

Simulation results for the HI management future are different from the CD, PM, and AM because, in addition to using an HI Scenario File, the HI management future simulation used the Historical CRBSUM PVT Cover Type and Structural Stage Maps as initial input data layers instead of the Current CRBSUM vegetation maps. Therefore, all initial HI cover type and structural stage predictions are not directly comparable to other futures, only the trends should be compared. The HI future is meant to describe the trajectory of landscape changes from the turn of the century to now in the absence of human activity.

Management Future Simulation Results

Tabular Summaries—The graphs presented in figures 8, 9, and 10 summarize tabular data generated by CRBSUM for the four management futures. Data used to create these graphs were summarized from CRBSUM output files using commercial statistical software. Figures 8a to 8e present the predicted area (km^2) of five cover types by four management futures (HI, CD, AM, and PM). These cover types were selected to represent common and rare forest and rangeland types across Interior Columbia River Basin. The large differences in land area coverage between cover types prevented the standardization of the Y-axis. In general, there is an increase in the area of ponderosa pine cover type in all futures with the HI future having the greatest portion of the landscape in the ponderosa pine cover type (fig. 8a).

Interestingly, Douglas-fir cover type decreases in all but the HI scenario (fig. 8b). The greatest decrease in Douglas-fir is in the AM future. The decrease in Douglas-fir is mainly in those PVT's where Douglas-fir

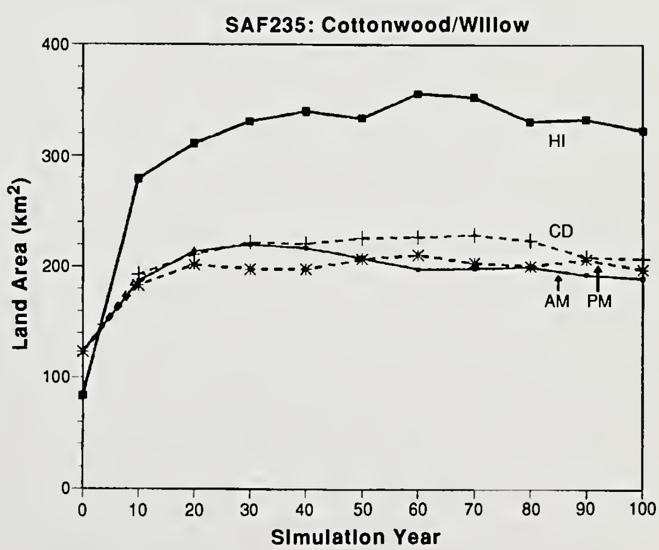


Figure 8c—Predicted land area (1,000 km^2) for cottonwood/willow cover type across the entire Interior Columbia River Basin.

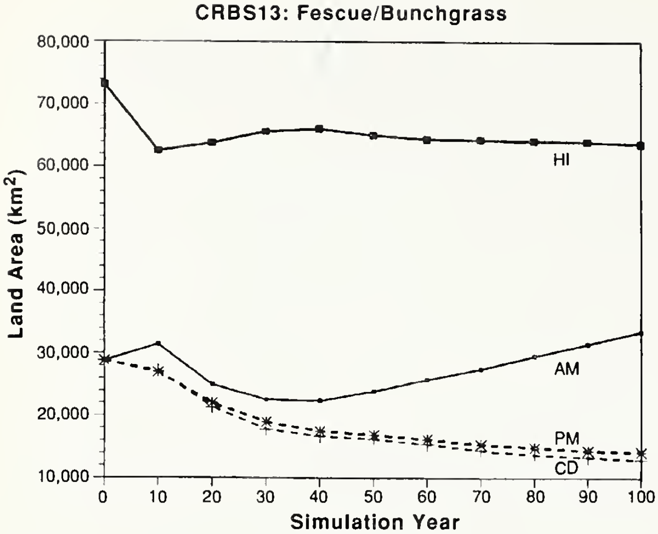


Figure 8d—Predicted land area (1,000 km^2) for fescue/bunchgrass cover type across the entire Interior Columbia River Basin.

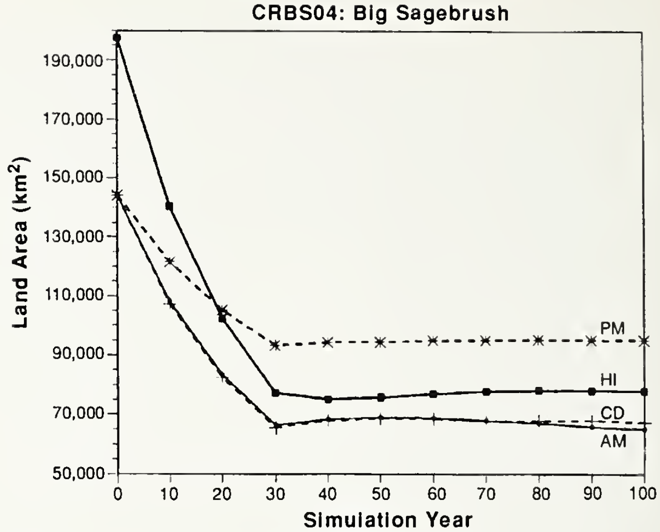


Figure 8e—Predicted land area (1,000 km^2) for big sagebrush cover type across the entire Interior Columbia River Basin.

is a seral species. Although the cottonwood/willow cover type is not common in the Interior Columbia River Basin, it increases in the first 20 years to double the starting coverage, except for the HI future where its coverage is tripled (fig. 8c). The fescue/bunchgrass cover type area stays somewhat constant across the 100 years of simulation, but big sagebrush drops dramatically after the start of simulation to a constant value of one fourth of the initial coverage after 30 years (fig. 8d and 8e). This loss of sagebrush is mainly a result of conversion to exotic types under the CD, AM, PM, and conversion to fire-dominated grasslands in the HI.

Major shifts in structural stages on the Interior Columbia River Basin landscape are demonstrated in figures 9a to 9f. The HI simulation predicts a decline in stand initiation structural stage (fig. 9a) with a corresponding increase in the old growth, single strata (fig. 9f) (see appendix C). The opposite is true for the other futures. The young forest, multistrata under the HI management future remains relatively constant but it decreases under the other futures (fig. 9d).

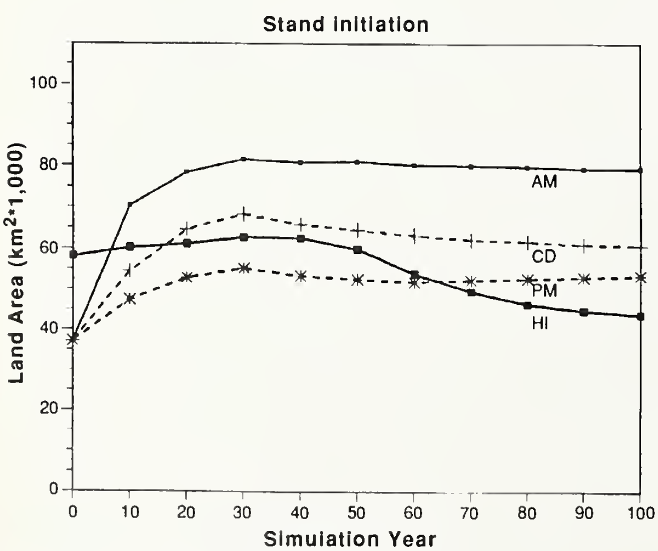


Figure 9a—Predicted land area (1,000 km^2) for forest stand initiation (SI_F) structural stage. Management futures are defined in table 2.

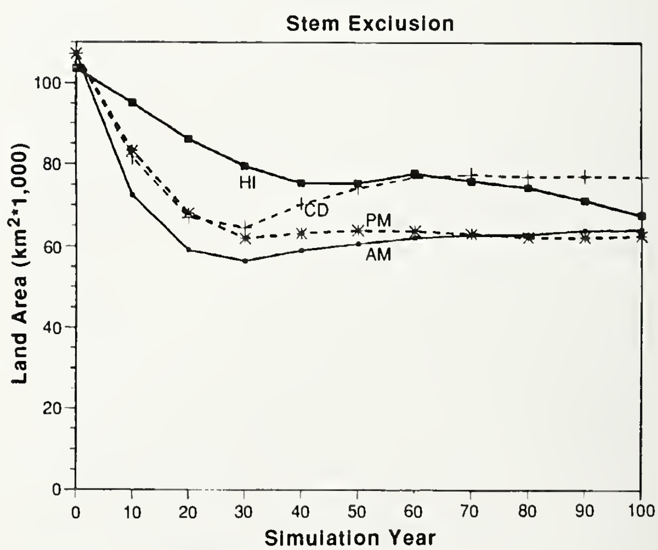


Figure 9b—Predicted land area (1,000 km^2) for forest stem exclusion (SEO_F and SEC_F).

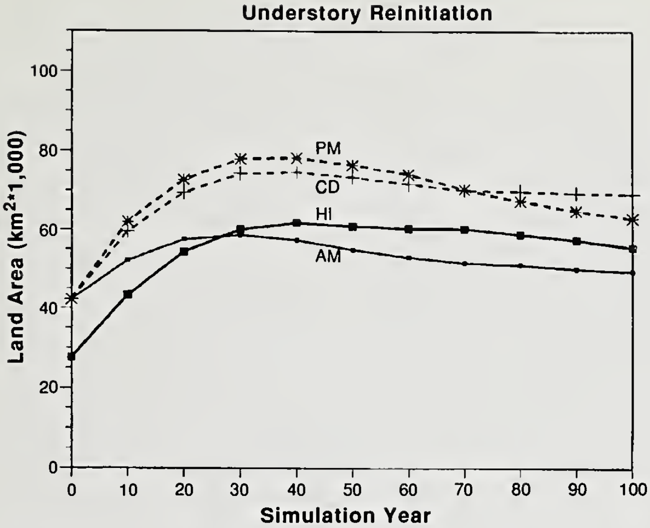


Figure 9c—Predicted land area (1,000 km^2) for the forest understory initiation (UR_F) structural stage.

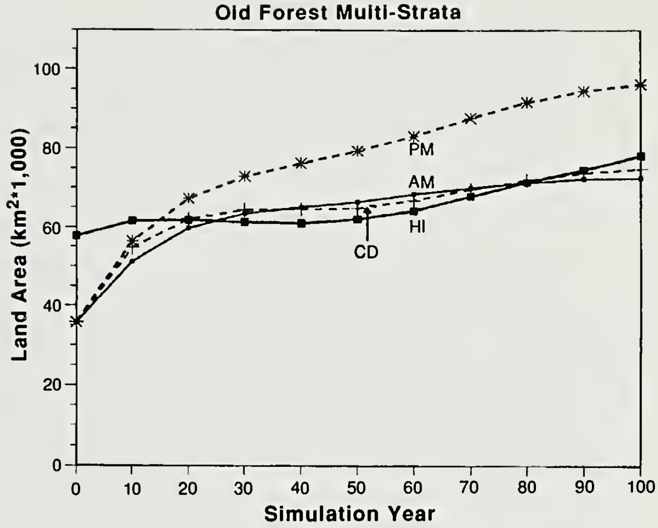


Figure 9e—Predicted land area (km^2) for forest old growth, multistrata structural stage (OMS_F).

The PM future has an abundance of stem reinitiation (fig. 9c) and old growth, multistrata structural stages (fig. 9e) which are in the advanced stages of succession. The CD and PM simulations produce the greatest amount of young multistrata forests, which is mostly a result of forest harvesting practices (fig. 9d). The stem exclusion structural stages (fig. 9b) drop drastically in the first 20 years of simulation for all futures and remain somewhat constant after simulation year 30.

Disturbance simulation results are shown in figure 10 where individual disturbance codes were aggregated to four general categories: (1) Fire (fig. 10a), (2) Insects and Disease (fig. 10b), (3) Grazing (fig. 10c), and (4) Harvest (fig. 10d). Each category contains many similar disturbances as presented in appendix D. The incidence of fire is much lower in the CD and PM futures because of active fire suppression (fig. 10a). The AM future maintains fire on the landscape at near historical levels. Insects and diseases are highest

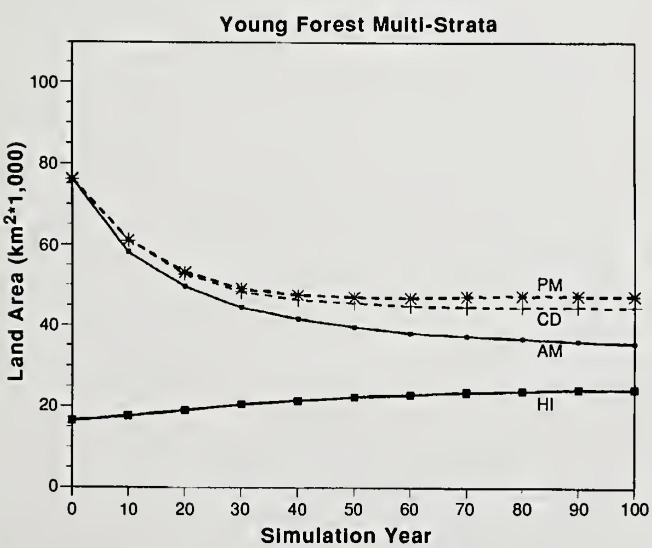


Figure 9d—Predicted land area (km^2) for forested, young forest multistrata structural stage (YMS_F).

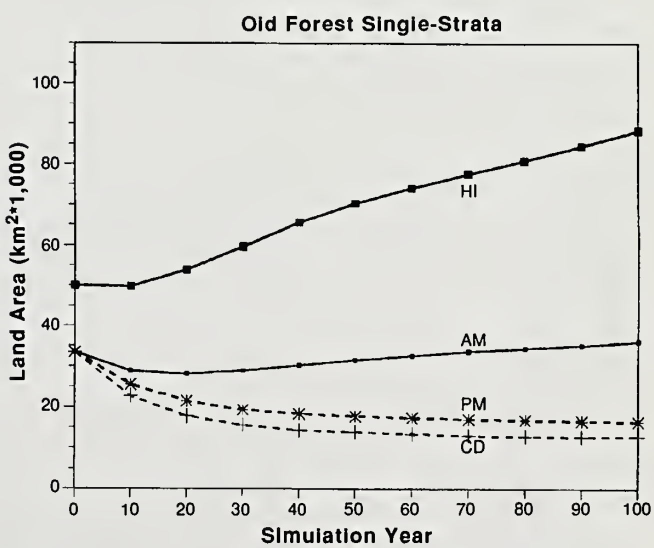


Figure 9f—Predicted land area (1,000 km^2) for forest old growth, single strata structural stage (OSS_F).

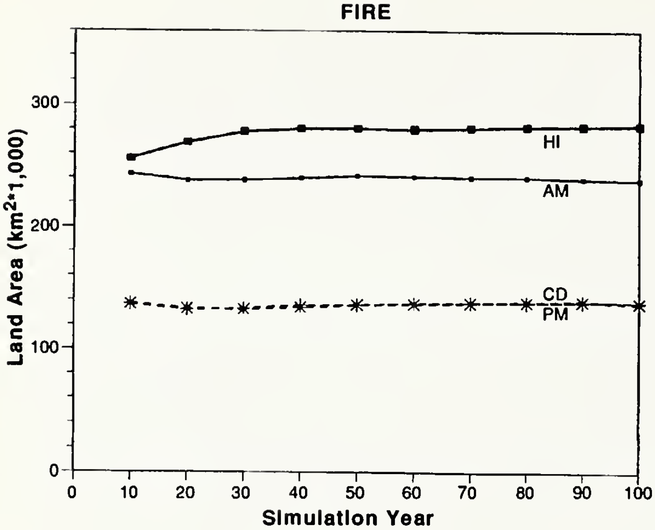


Figure 10a—Land area (1,000 km^2) affected by all fire disturbances (combined) as predicted by CRBSUM.

under the HI simulation, probably because of mountain pine beetle epidemics (fig. 10b).

The smallest area affected by insects and disease is under the AM future where prescribed fire is the primary tool to restore historical fire regimes. Insect and disease disturbances affect the least amount of land area in this modeling effort for all futures. Grazing disturbances are highest in the AM and CD futures and lowest in the HI and PM futures. This is because livestock grazing is a featured activity in the CD management future. Timber harvesting activities are,

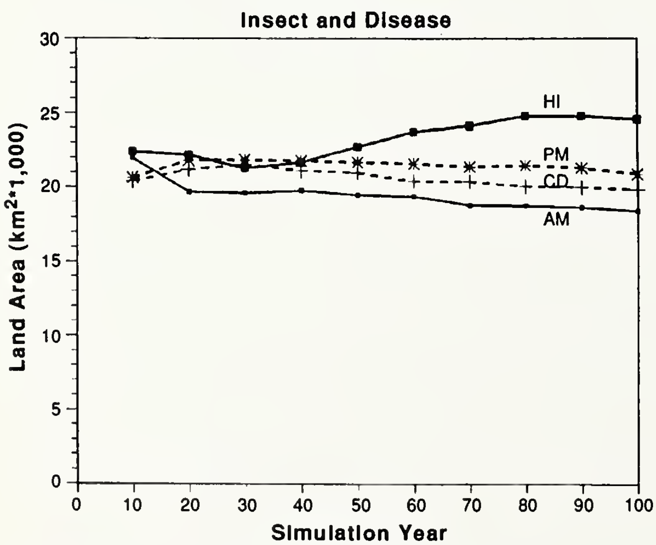


Figure 10b—Land area (1,000 km^2) affected by insects and disease disturbances as predicted by CRBSUM.

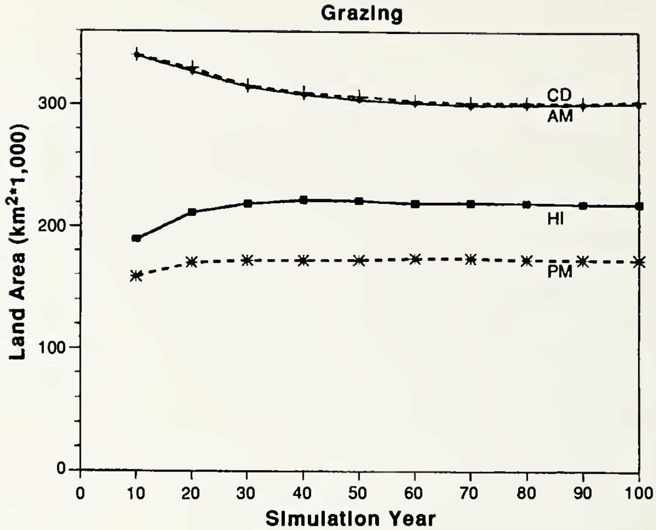


Figure 10c—Land area (1,000 km^2) affected by all grazing disturbances as predicted by CRBSUM.

of course, highest in the CD future. However, harvest disturbances are also common in the AM future because silvicultural activities are used as a tool for ecosystem restoration. There is no harvesting in the HI future.

Spatial Summaries—Predicted cover type maps from the CD management future predictions are shown in color plates 5a-d. Most landscape change from initial conditions to simulation year 10 is in the conversion of rangelands to exotics (color plate 5a). Exotics were not explicitly mapped in the Current Cover Type Base Map

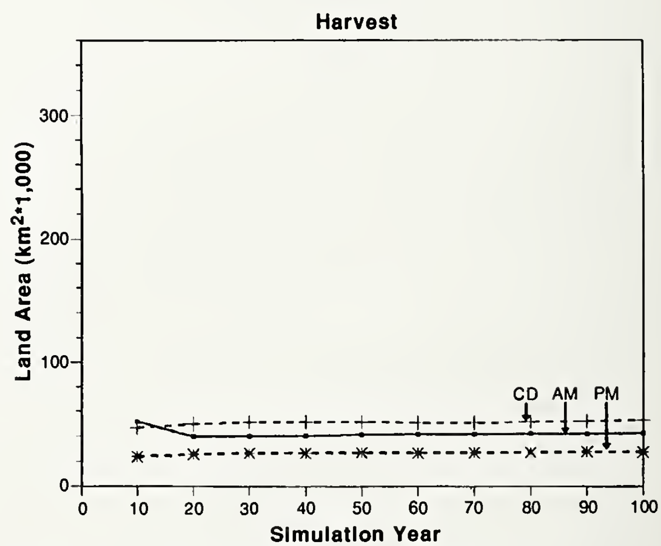
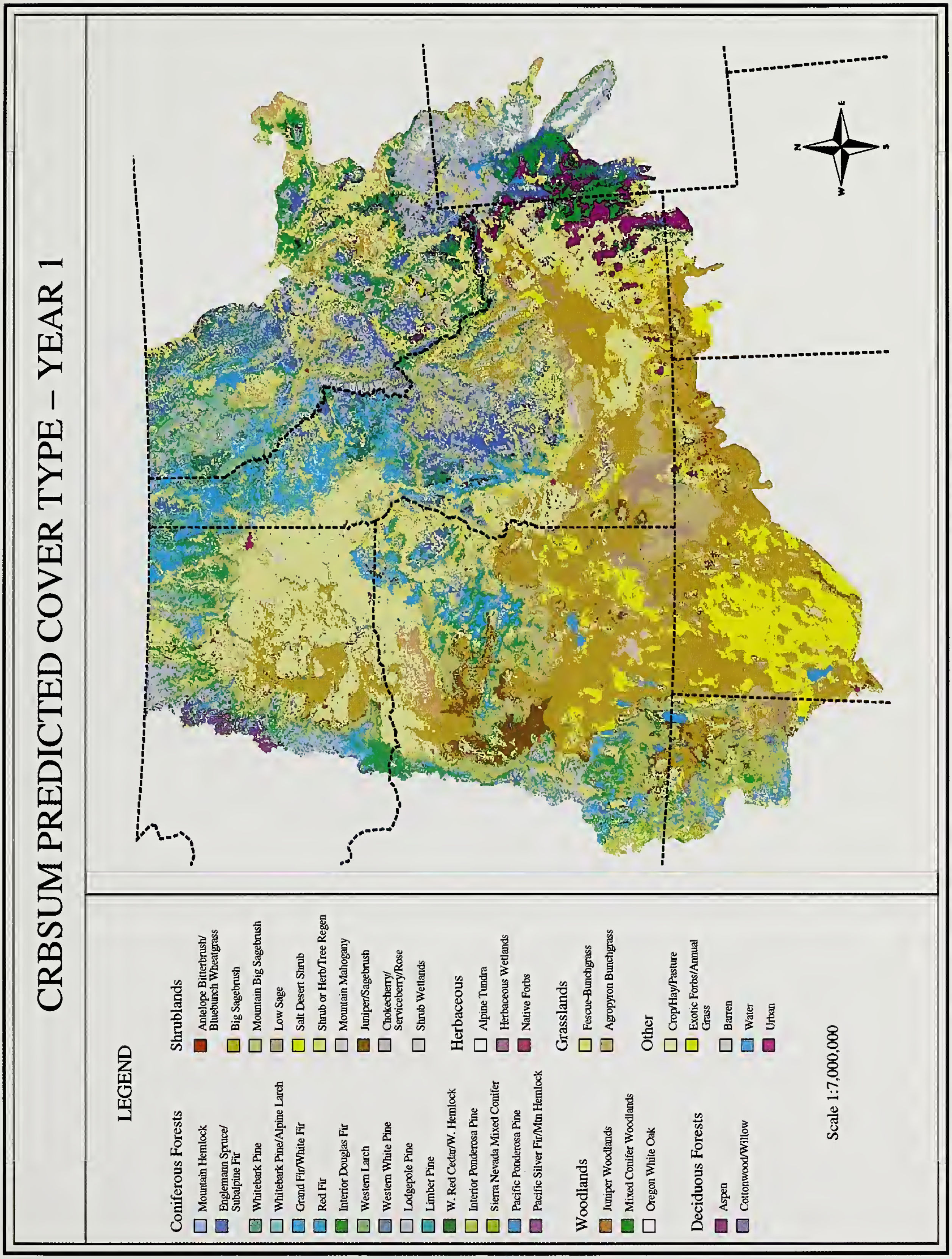
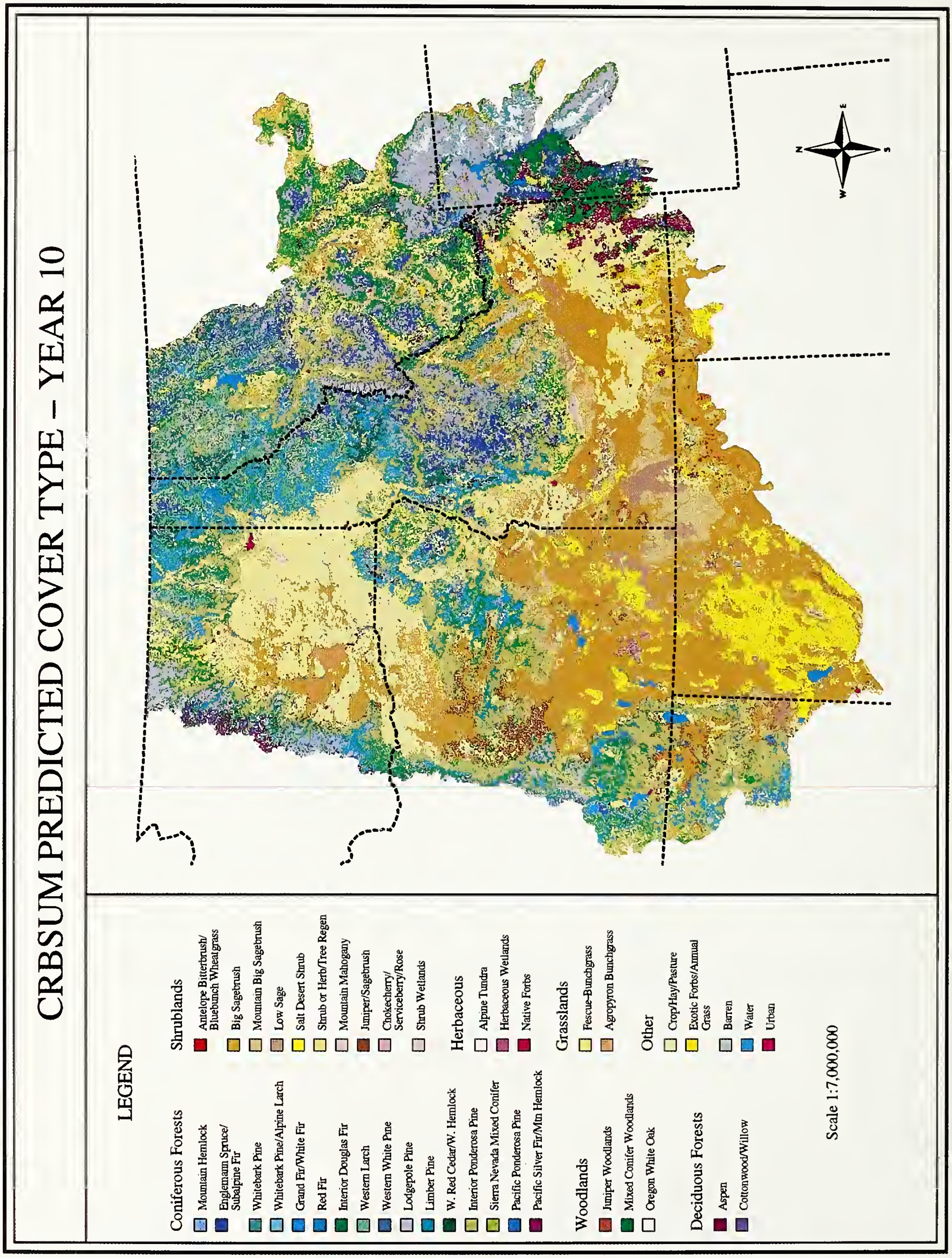


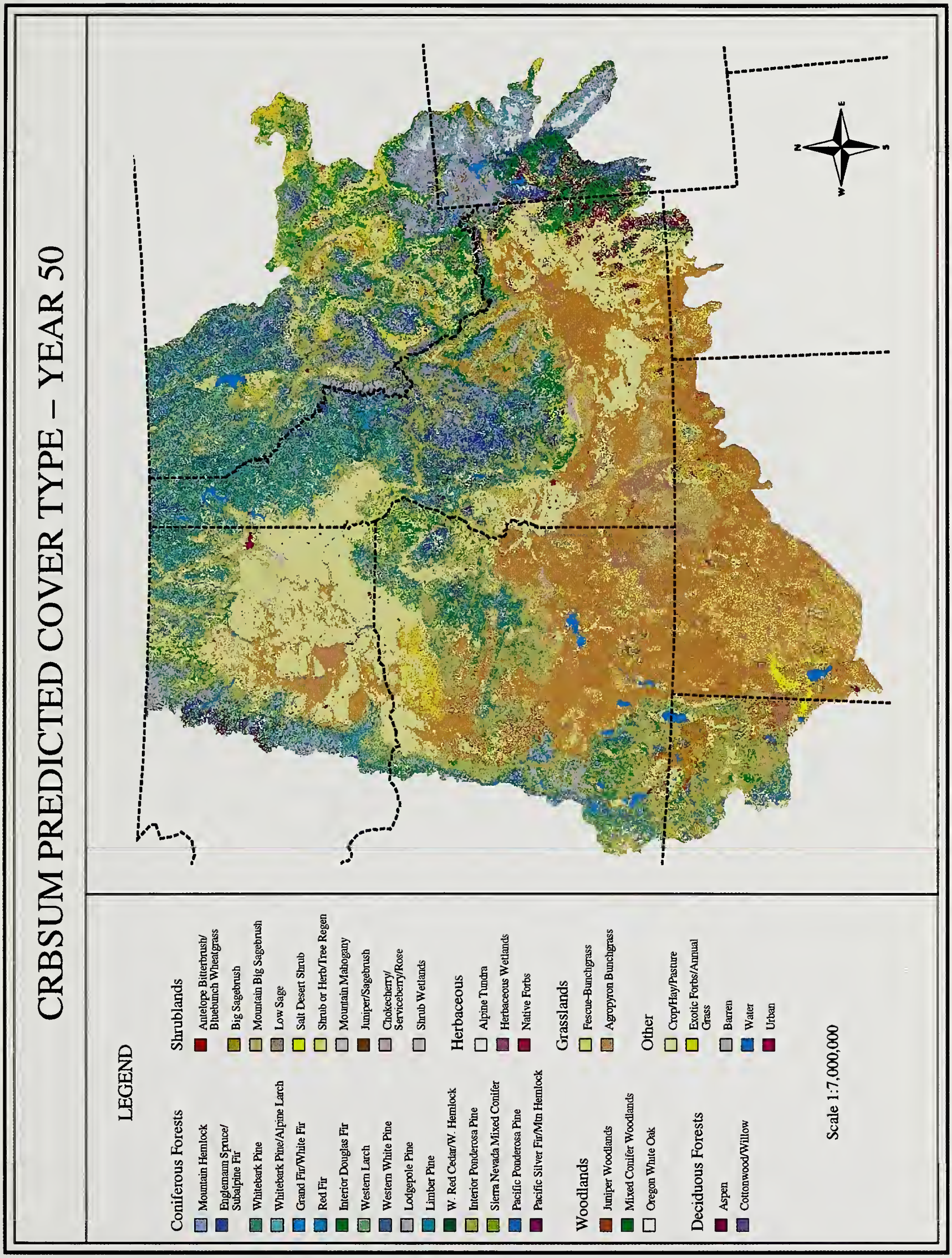
Figure 10d—Land area (1,000 km^2) affected by all harvest disturbances as predicted by CRBSUM. No harvests were included in the HI simulation.



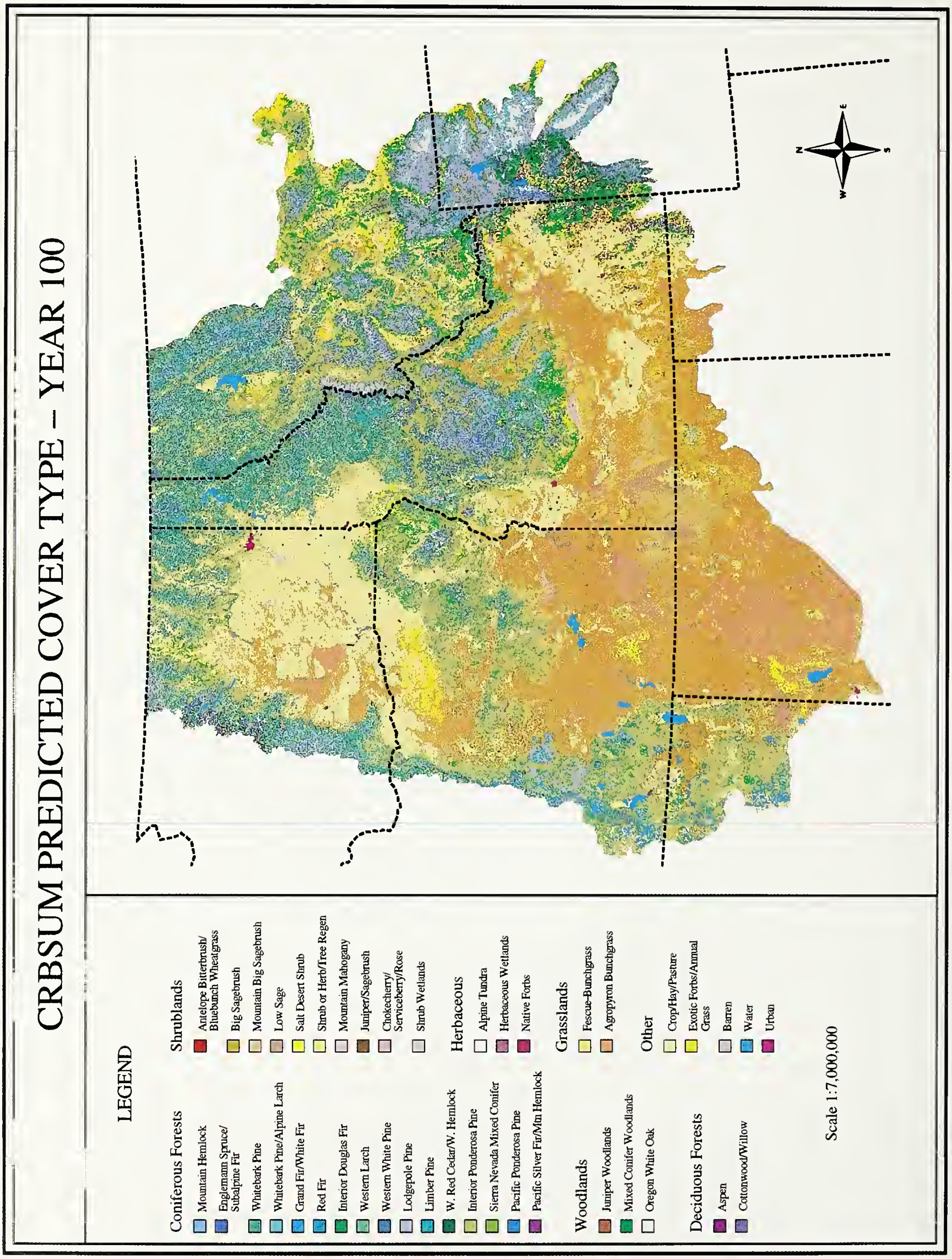
Color plate 5a—Map of predicted Interior Columbia River Basin Cover Type groups created by CRBSUM for simulation year 1.



Color plate 5b—Map of predicted Interior Columbia River Basin Cover Type groups created by CRBSUM for simulation year 10.



Color plate 5c—Map of predicted Interior Columbia River Basin Cover Type groups created by CRBSUM for simulation year 50.



Color plate 5d—Map of predicted Interior Columbia River Basin Cover Type groups created by CRBSUM for simulation year 100.

(Hardy and others, in preparation) so most land areas having PVT's containing exotic cover types in the successional pathway diagram were converted to exotics within the first decade. Changes in low elevation forested areas are evident by year 10 (color plate 5b) with some ponderosa pine cover type pixels being replaced by Douglas-fir. Mid-elevation shifts from older forests to early seral forests due to fire and harvest are apparent by year 50 (color plate 5c). By year 100 it is evident that most mature seral species cover types have either been harvested or allowed to successionally advance to shade-tolerant species (color plate 5d).

Sensitivity Results

Simulation Variability—The range of variability of CRBSUM land area predictions for five cover types across 100 individual simulations with a static Initial Age Map are shown in table 2. There was little variation between CRBSUM runs across all simulation years. Cover type projections with the greatest variations usually do not comprise much of the landscape (such as cottonwood/willow) and tend to have infrequent, severe disturbances such as stand-replacement fires in big sagebrush (table 2). This variability is probably because the number of pixels encompassing rare cover types is so small that the loss of one pixel from that cover type causes a high percent change. For example, the loss of 1 pixel from a cover type comprising 10 pixels is 10 percent, while the same loss is only 1 percent of a cover type comprised 100 pixels. Severe disturbances nearly always result in a change of cover type. Generally, run-to-run variation increases toward the end of the simulation period, and also as cover types decrease in aerial extent (table 2). It is often only one or two simulations out of 100 that increase the between-run variability (table 2).

Parameter Sensitivity—The sensitivity of CRBSUM simulations to a 25 percent increase in selected disturbance probabilities is presented in table 3 for five cover types. Results from the entire sensitivity analysis were too lengthy for inclusion here. Summarized results show only minor differences in cover type projections with major changes (25 percent) in the disturbance probabilities. Modifications to parameters of frequent, low severity disturbances such as grazing (table 3) usually caused the greatest short-term differences in cover type predictions (0 to 20 percent). Changes in infrequent, moderately severe disturbance parameters, such as mountain pine beetle epidemic probabilities, can cause a large differences in cover type coverage between simulations, but only if the epidemic occurred in the 100 year simulation period. Frequent, high severity disturbances such as fire can cause moderate differences between simulation

Table 2—CRBSUM variability analysis results for selected cover types in Yakima Drainage Basin with initial age map held constant. Coefficient of variation is standard deviation divided by mean times 100.

Cover type	Year	Mean	Standard error	Minimum	Maximum	Coefficient variation
		-----------------	-----------------	km^2	-----------------	*Percent*
Ponderosa pine	1	2,006.8	1.407	1,997	2,007	0.07
(SAF 237)	10	1,854.2	1.407	1,854	1,864	0.07
	50	1,493.3	1.970	1,493	1,507	0.13
	100	1,383.3	2.392	1,383	1,400	0.17
Douglas-fir	1	1,266.5	3.841	1,266	1,297	0.30
(SAF 210)	10	1,038.7	4.784	1,038	1,072	0.46
	50	941.1	14.633	939	1,043	1.55
	100	1,017.9	0.844	1,012	1,018	0.08
Cottonwood/willow	1	61.0	0.281	59	61	0.46
(SAF 235)	10	54.0	0.281	54	56	0.52
	50	46.1	0.985	46	56	2.13
	100	43.8	1.126	36	44	2.57
Big sagebrush	1	3,361.9	0.985	3,355	3,362	0.03
(CRB S04)	10	2,217.1	0.704	2,217	2,222	0.03
	50	1,304.4	3.940	1,277	1,305	0.30
	100	1,206.1	14.287	1,138	1,294	1.18
Fescue/bunchgrass	1	68.1	0.704	68	73	1.03
(CRB S13)	10	116.9	0.704	112	117	0.60
	50	103.1	0.563	103	107	0.55
	100	93.8	3.225	63	100	9.04

Table 3—Results of a sensitivity test of CRBSUM to disturbance parameters. Table values are percent change in land area when an individual disturbance probability is increased by 25 percent.

Cover type	Disturbance	Year 1	10	50	100
Ponderosa pine (SAF 237)	Mountain pine beetle	0.0	0.0	0.0	0.1
	Livestock grazing	0.0	–1.1	12.7	2.5
	Stand-replacement fire	0.0	1.0	4.4	0.4
	Clearcut—no site prep.	0.0	0.0	3.2	–2.1
Douglas-fir (SAF 210)	Mountain pine beetle	0.0	–0.2	–0.8	0.0
	Livestock grazing	0.0	–1.5	–0.6	1.6
	Stand-replacement fire	0.3	2.5	–4.4	–2.1
	Clearcut—no site prep.	0.0	–0.3	1.8	–1.2
Cottonwood/willow (SAF 235)	Mountain pine beetle	0.0	0.0	0.0	0.0
	Livestock grazing	0.0	–3.7	–23.9	–27.3
	Stand-replacement fire	0.0	9.3	–17.4	0.0
	Clearcut—no site prep.	0.0	0.0	–2.2	–13.6
Big sagebrush (CRB S04)	Livestock grazing	0.5	3.7	8.0	–1.5
	Stand-replacement fire	0.7	3.3	9.4	6.1
Fescue/bunchgrass (CRB S13)	Livestock grazing	0.0	14.5	–4.1	–6.5
	Stand-replacement fire	–2.9	0.9	2.7	3.9

runs with deviations greatest at the 50 year mark (such as with the Douglas-fir and big sagebrush cover types, table 3). Again, those cover types having less than 500 pixels seem to be most sensitive to changes in disturbances probabilities.

CRBSUM Test Results

Comparison of the Current CRBSUM Cover Type Map (Observed) with the cover type map predicted by CRBSUM at simulation year 100 under a Consumptive Demand management future (Predicted Area) is shown in table 4. Generally, CRBSUM predicted comparable cover type area estimates within 50 percent of the observed about 70 percent of the time as weighed by historical number of pixels. This was much better than expected considering the inaccuracies of the Historical and Current Cover Type Base Maps, and the mismatch of the Consumptive Demand future with Interior Columbia River Basin land management policies of the last 100 years. Only a few cover types (whitebark pine/alpine larch, western white pine, table 4) were in great disagreement between predicted and observed. These cover types have had major infections by an introduced disease, white pine blister rust, over the last 80 years, and this disturbance was probably not accurately parameterized in the CD Scenario File. Overall, most predictions were well within an order of magnitude of the historical observations, which is quite acceptable considering the resolution of the input data and raster maps. The same general trends were evident when the 100 year CRBSUM cover type map was compared with the Hardy and others (in preparation) Cover Type Base Map.

Discussion

CRBSUM Model

High input data quality is essential for the successful simulation of any CRBSUM management future or alternative. It is critical that succession pathway and disturbance parameters be tested, compared and validated with the Vegetation Dynamics Development Tool (VDDT) program and field data before they are used in CRBSUM. Publications, vegetation databases, and expert knowledge can be used to confirm the validity of most model parameters. Existing regional databases detailing land area treated by past management activities are especially valuable as CRBSUM validation information for the disturbance probabilities in the Scenario File. A technical review of succession pathways and disturbance parameters by ecological experts is another useful validation tool. Lastly, simulation results should be compared with published findings to ensure output is reasonable and the model is behaving correctly.

Summarization of CRBSUM predictions should be done in the context of their stratification. For example, one interpretation of the increase in ponderosa pine cover type (fig. 8a) and the decrease of Douglas-fir cover type (fig. 8b) is that ponderosa pine is not being replaced by Douglas-fir in the CD management future as previously thought (Mutch and others 1993).

Table 4—CRBSUM test results contrasting land area (km^2) in the Current Cover Type Base Map (observed) and CRBSUM cover types (predicted) under Consumptive Demand management future after 100 years.

Cover type code	Cover type description	Observed area	Predicted area	Percent difference[1]
		- - - - - - - *km²* - - - - - - - -		
CRB003	Shrub or herb/tree regeneration	36,746	25,617	30
CRB005	Alpine tundra	3,727	3,729	0
CRB006	Barren	2,299	2,299	0
CRB007	Herbaceous wetlands	1,316	2,766	–110
CRB008	Pacific silver fir/mountain hemlock	2,315	957	58
CRBS01	Juniper woodlands	1,296	4,140	–219
CRBS02	Mixed conifer woodlands	3,928	25,452	–547
CRBS03	Juniper/sagebrush	15,348	1,122	92
CRBS04	Big sagebrush	144,090	96,305	33
CRBS05	Wetland/shrub	2,906	547	81
CRBS06	Agropyron bunchgrass	17,265	144,744	–738
CRBS07	Native forb	51	250	–390
CRBS08	Exotic forbs/annual grass	11,378	62,316	–447
CRBS09	Grand fir/white fir	31,144	7,306	76
CRBS10	Whitebark pine/alpine larch	99	6,771	–6,739
CRBS11	Red fir	36	146	–305
CRBS12	Cropland/hay/pasture	118,363	8,715	92
CRBS13	Fescue/bunchgrass	28,840	15,370	46
CRBS19	Urban	1,143	0	100
CRBS20	Water	7,550	7,561	0
SAF205	Mountain hemlock	1,272	1,198	5
SAF206	Spruce/subalpine fir	37,306	25,735	31
SAF208	Whitebark pine	9,352	13,258	–41
SAF210	Interior Douglas-fir	69,947	50,665	27
SAF212	Western larch	13,705	26,618	–94
SAF215	Western white pine	462	9,732	–2,006
SAF217	Aspen	17,160	4,302	75
SAF218	Lodgepole pine	64,113	55,629	13
SAF219	Limber pine	412	266	35
SAF227	Western red cedar/western hemlock	3,926	1,831	53
SAF233	Oregon white oak	658	413	37
SAF235	Cottonwood/willow	123	389	–216
SAF237	Interior ponderosa pine	75,823	137,824	–82
SAF243	Sierra Nevada mixed conifer	1,843	706	62
SAF245	Pacific ponderosa pine	2,669	3,366	–26
SRM104	Bitterbrush/bluebunch wheatgrass	1,295	64	95
SRM322	Mountain mahogany	2,247	2,154	4
SRM402	Mountain big sagebrush	38,578	36,952	4
SRM406	Low sage	15,054	19,881	–32
SRM414	Salt desert shrub	35,368	13,970	60
SRM421	Chokecherry/serviceberry/rose	207	294	–42

[1]Percent difference = 100 * (observed-predicted)/observed.

However, when results are stratified by PVT, it is evident that the Douglas-fir cover type is increasing in coverage and the ponderosa pine cover type is decreasing in Douglas-fir PVT's. It is in the mesic PVT's (such as cedar/hemlock, grand fir) where Douglas-fir is increasing in cover. In addition, when this information is stratified by structural stage, it is evident that old growth, single strata ponderosa pine stands that were historically maintained by fire, are reduced to 10 percent of their historical coverage under the CD management future. Most of these stands are being replaced by Douglas-fir and young, multistrata ponderosa pine cover types. This is probably a result of timber harvest activities and the exclusion of fire. So, the finer detail in model predictions can provide a means to understand and interpret CRBSUM results, particularly at the coarser scales.

Most disturbance maps generated by CRBSUM are not especially useful for accurately portraying year-to-year disturbance spatial distributions. These maps are most functional in depicting general geographic trends of disturbance events rather than the identification of specific locations where a disturbance occurred. However, CRBSUM disturbance maps can be used to assess long-term spatial arrangement of various disturbances on the Interior Columbia River Basin landscape, even without a contagion component built into CRBSUM disturbance simulations. Contagion is indirectly included in CRBSUM through the use of the static PVT layer. All disturbance probabilities are stratified by PVT and these types are constant on the coarse-scale landscape. Therefore, PVT's with frequent disturbances, such as fire, will tend to have more fire occurrences on the fire disturbance map.

The time scales used to summarize CRBSUM predictions directly influence the interpretation of simulation results. Fine temporal scales (such as an annual time step) will show year-to-year variation in model predictions and long term trends may be masked. These annual variations are especially useful for quantifying the "natural range of variability" within ecosystems. Coarser time scales (such as decades) will tend to portray ecosystem trends rather than annual variability, and results summarized at this scale are more useful for contrasting management alternatives.

The volume of output generated from a CRBSUM simulation can be overwhelming. The model has the potential of creating eight data layers and updating three data files for every year of simulation. The Interior Columbia River Basin simulation effort yielded some 120 megabytes of map layers and 130 megabytes of data files for each management future. Therefore, it is essential that a plan be developed to manage simulation information. Relational database management systems and GIS libraries are some software tools that can be used to manage, query, analyze, and summarize output data.

Sensitivity Analysis and Test Results

Variability associated with the averaging of multiple runs was surprisingly low. This is probably a result of the random number generator used in the CRBSUM program. This algorithm was taken from Press and others (1992) and has been extensively tested for random behavior by Press and others (1992) and by this Interior Columbia River Basin simulation effort. Generated random numbers are apparently random within a simulation run, but the series of numbers generated across runs seem to differ only slightly. This random number sequence seems to repeat across simulations resulting in low, across-run prediction variability. Other random numbers were tested, but the same or worse behavior resulted. Random number generators are an essential component of stochastic models and their random behavior is required for results comparison. The repeated series of random numbers across simulation runs probably allowed a more accurate comparison of CRBSUM predictions.

Sensitivity of CRBSUM predictions to changes in disturbance probabilities was also quite low. A 25 percent increase in probability caused only an average of 5 percent change in cover type aerial extent. This was encouraging because most probabilities were estimated from the "best guesses" of resource professionals and could have frequently been in error. A range of ±25 percent seems a satisfactory margin of error for most disturbance probability estimates.

Comparison of the Current Cover Type Base Map with cover type map predicted by CRBSUM for year 100 using the Historical input maps and CD management future produced promising but unsatisfactory results. Inherent errors in historical data layers, CD disturbance probabilities and current cover type map, are probably the cause of many inconsistencies. Refinement of PVT successional pathway parameters and spatial data will produce better results for future simulations. Development of a management future that more accurately reflects the last 100 years of management in the Interior Columbia River Basin will also help.

Interior Columbia River Basin Simulation Effort

It is difficult to generalize about the complex, extensive and detailed predictions generated by CRBSUM for the entire Basin by this simulation effort. Instead, this section will discuss the interpretation of these results relative to CRBSUM simulation characteristics to profile the use of the model for future simulation projects.

A comparison of management future simulation results reveals several important coarse-scale land

management consequences (figs. 8, 9, 10). Any future having extensive fire suppression policies (CD, PM) usually results in increases of (1) shade tolerant cover types, (2) late seral, multistrata structural stages, and (3) insect and disease occurrence. Conversely, without wildland fire there is usually decreases in (1) shade intolerant species, (2) old growth, single strata structural stages, and (3) frequent, low severity disturbances. The timber harvest activities featured in the CD management future tend to create an abundance of young, multilayered stands of shade-tolerant species. Exotic plant cover types quickly dominate most native plant communities in the three current management futures (CD, AM, PM), and this conversion is especially rapid when grazing is a featured disturbance (CD, PM).

The AM future attempts to mimic historical processes using creative timber cutting and prescribed burning treatments. However, predicted cover type and structural stage land area under the AM future do not match HI predictions in some cases. This is probably because fire suppression activities were integrated into the AM probabilities for most PVT's. It was unrealistic to harvest trees or prescribe burn the vast acreage that would have been burned by historical fire regimes in the AM future because of the immense cost of treatment. It was also unreasonable to let wildfires burn on the intensively managed landscape because of increased rural settlement, loss of timber value, and threat to human life. Therefore, the set of fire probabilities designed for the AM scenario include a reduction for fire suppression. This probability reduction is probably the reason AM trends do not match HI trends in magnitude.

The HI management future simulation results do not always seem reasonable for some cover types and structural stages. Many cover types and structural stages were expected to remain somewhat stable in extent over the 100 years of simulation. Instead, CRBSUM predicted major changes in landscape vegetation over the first 10 to 30 years. This is probably a result of limitations in the input disturbance probabilities and spatial data layers. Estimating historical disturbance probabilities proved to be an extremely difficult task. Studies of fire history were conducted mostly in forested ecosystems and are usually limited to the last 2 to 3 centuries. Little data exist to quantify historical frequency and severity of insect and disease perturbations for all ecosystems in the Interior Columbia River Basin. Moreover, the relationship of insects and disease to fire is also poorly understood for most biomes on the historical landscape.

The Historical CRBSUM Structural Stage and Cover Type Maps used to quantify initial conditions in CRBSUM were probably inaccurate for some geographical areas. The Historical CRBSUM Cover Type Map was created from a paucity of historic vegetation information. These data were collected at different scales using different methods and often for only selected land areas (Losensky 1994). Many historical classifications of cover type did not match those used for the Interior Columbia River Basin scientific assessment. In addition, most archived information concerned only Federal forested lands (Losensky 1994). The Historical CRBSUM Structural Stage Map also contains a high degree of error because of the statistical method used to create the map. Stochastically assigning structural stage from archived information stratified by cover type and geomorphological landform is not the most desirable method, but it was the only one possible due to Interior Columbia River Basin time constraints. These historical structural stage data were not stratified by PVT or any other biophysical description. In addition, structural stages were independently assigned to pixels with no treatment of the spatial autocorrelation of structural stage on the landscape. These inadequacies probably resulted in a highly inaccurate historical structural stage layer.

CRBSUM Limitations

Model Design—There are many limitations in CRBSUM model design and input parameters that should be taken into account when interpreting model predictions. First and probably most importantly, disturbance processes on the coarse-scale landscape are simulated at the pixel level as independently occurring events. This approach does not allow for the spread of major disturbances that may affect large land areas in one event such as fire or insects. Disturbance processes that have contagion properties (dependency on surrounding pixels) are not accounted for in CRBSUM design because the model only simulates disturbance on one pixel and does not assess attributes of those pixels that surround the pixel in question.

In addition, the model does not include other contagion factors such as proximity to roads and topographic position that will directly affect a disturbance process. The result is that short-term disturbance mapping is not authentically modeled in CRBSUM.

Another disturbance simulation limitation is the inability of CRBSUM to simulate the synchronicity of large-scale perturbations. A majority of area burned by fires seem to occur in especially dry years and this temporal relationship is not built into CRBSUM design (Baker 1989). However, long-term, cumulative disturbance occurrences tend to exhibit some "pseudo-contagion" on the coarse-scale landscape because disturbance probabilities are stratified by PVT's and the spatial distribution of PVT's is static. Consequently, all disturbance maps generated from CRBSUM should be treated as visualization aids that illustrate what areas are relatively different in disturbance simulation.

A disturbance contagion model called DISCONT was developed for the Interior Columbia River Basin simulation effort to be included in the mid-scale CRBSUM simulations, but quantifying parameters for the major disturbance probability functions could not be done in the short time allowed for the scientific assessment.

Disturbance simulation in CRBSUM is accomplished using a uniform probability distribution that may not always be appropriate for many management actions. The occurrence of a disturbance event is governed by its underlying probability distribution and the factors that control the incidence of that disturbance. For example, the probability of fire occurrence is often modeled using a three-parameter Weibull probability density function with time since last fire as a major independent variable (Baker 1989; Johnson and Van Wagner 1985; Van Wagner 1978). CRBSUM treats each disturbance occurrence as an independent event from a uniform probability distribution. It then sums probabilities from many disturbances to generate a cumulative probability distribution. This may be an oversimplification for some coarse-scale perturbations because it does not account for other factors controlling disturbance occurrence such as contagion and climate.

Simulations of extensive landscapes (greater than 1 million pixels) using CRBSUM can take great amounts of time and computing resources. Execution times of 2 to 3 days, as experienced in the Interior Columbia River Basin effort, does not allow efficient refinement of model parameters through trial-and-error. Reducing the number of pixels requires some aggregation and smoothing that may affect the integrity of spatial data. A compromise between landscape resolution and computing efficiency is needed to achieve the best simulation results. We recommended that CRBSUM be used in a two step process where the first step involves using the model to refine input parameters to obtain reasonable predictions, and the second step is the actual simulation of various scenarios that represent land use policies. A simulation landscape of approximately 500 pixels by 500 pixels is probably an optimum size to balance execution time with landscape complexity at the current time. As computers get more powerful, this size can increase proportionately.

Application of CRBSUM to fine scale planning is a complex and demanding task. The process of producing input parameters for CRBSUM simulation and creating the needed data layers requires abundant time and computer resources. Succession pathway parameters must be quantified for each PVT in the analysis area and then disturbance probabilities must be consistently estimated by each PVT, succession class, and management scenario. Spatial data layers of PVT, cover type, and structural stage must be created and then rectified to agree with the developed succession pathways for the entire area. Validation data must be gathered to compare with CRBSUM predictions to ensure proper model behavior. This entire process could take many months to complete. Perhaps the most difficult task is finding PVT, successional, disturbance, and spatial information for all ecosystems on the landscape in a consistent method.

The successional pathway diagrams that serve as the foundation of CRBSUM are only generalized models of successional development within a PVT and may not provide sufficient detail to answer some critical management questions. These pathways coarsely describe successional trajectories and dynamics, and sometimes important successional information can be lost in the generalization used for CRBSUM structure. An example might be the treatment of dwarf mistletoe in lodgepole pine cover types in a subalpine PVT. It was decided that the effect of dwarf mistletoe on successional dynamics was not included in successional pathway diagrams because its impact is not important at the coarse-scale used in PVT development and mapping. Therefore, management concerns about dwarf mistletoe effects on lodgepole pine forests could not be answered using CRBSUM simulation results.

Interior Columbia River Basin Simulation Effort—The Interior Columbia River Basin coarse-scale predictions generated by CRBSUM may not be directly applicable to fine-scale projects. The general nature of successional pathway diagrams and the method of disturbance simulation may limit the use of CRBSUM-generated maps in National Forest level planning. These output data are germane only to the context of National Forest planning rather than the details of plan implementation. For example, an appropriate query for generated coarse-scale data would be: "How much ponderosa pine is on my forest compared with all ponderosa pine in the Interior Columbia River Basin?" An inappropriate question might be "Where are the ponderosa pine stands on my forest?" CRBSUM tabular and spatial results are only conceptualizations, not field guides, and represent only one possible simulation future. Careful utilization and interpretation of these simulated data will be critical in future applications and National Forest plan revisions.

Nearly all successional and disturbance parameters were quantified by teams of "experts" from various resource fields in a workshop format. These people were gathered together in seven separate workshops to provide their "best guesses" for many CRBSUM parameters. This approach seemed to be successful at quantifying most CRBSUM parameters in a short time. Indeed, Stage and others (in preparation) used the stand growth model FVS to estimate and validate

some successional development parameters and found many of the expert estimates were comparable with FVS predictions.

However, there were problems with this "expert estimate" method of quantifying succession dynamics. First, the same level of expertise was not available for all PVT's and for all disturbance types. Consequently, the PVT's that were rarely studied or visited often had the least accurate successional parameters and the fewest experts to describe them. Knowledge of each disturbance process was seldom constant across all vegetation types. Some experts had vast knowledge of ponderosa pine forests and their fire regimes but had little knowledge of fire in whitebark pine cover types. As a consequence, disturbances such as fire were often modeled in great detail in some pathways and received only minor attention in other pathways. In addition, the HI and CD management futures were developed with more time and input from experts than the PM and AM futures.

The same people rarely attended all seven workshops. This resulted in a lack of consistency in parameter estimation across all workshops. Often, workshop groups ignored past workshop products and evaluated existing parameters rather than refine successional dynamics. As a consequence, some successional pathways lack disturbance processes that were specified in other pathways. These inconsistencies are prevalent in rangeland types as well as forest types. In addition, some workshop groups provided great detail in a PVT's successional pathway diagram while others simplified successional dynamics in a pathway by reducing detail and not including many important disturbances or succession classes.

The rapid pace required for the timely completion of the Interior Columbia River Basin scientific assessment did not allow for a comprehensive quality assessment of CRBSUM parameters. CRBSUM is as much a diagnostic tool as a prognostic tool and many successional pathway diagrams and disturbance probabilities could have been further refined if there had been time. Management future simulation should be an iterative process where preliminary results are evaluated as to acceptability, then parameters are refined to improve simulation predictions. Preliminary model results were not available for many succession workshops, so experts could not adjust questionable disturbance probabilities and successional pathway parameters, especially for the AM and PM futures. Lastly, there was only time to run CRBSUM once for each management future. As a result, there are some inconsistencies in PVT pathway dynamics that could have been resolved using preliminary CRBSUM output if there had been time.

Descriptions of coarse-scale potential vegetation types and cover types using plant species may be inappropriate for a coarse-scale application. A classification of vegetation types assumes the classified entity will not change significantly across the spatial and temporal resolution of simulation. In reality, there can be major changes in species composition across the square-kilometer pixel used in the coarse-scale simulation effort. Perhaps a more appropriate cover type classification may be a combination of life form and shade tolerance. For example, one pixel might be dominated by shade-tolerant trees while another may be composed of shade-intolerant shrubs. However, the annual time step used by CRBSUM is probably suitable for species-level simulations.

CRBSUM input maps need additional refinement and ground-truthing. Results from climate and ecosystem process models need to be compared to the biophysical settings map (Reid and others 1995) to validate the accuracy and precision of biophysical categories. Geo-referenced plot data need to be used as ground-truth for the cover type, structural stage, and PVT maps when appropriate. An extensive, coarse-scale, ground-truthing effort must be initiated to characterize cover type, structural stage, and PVT on a square kilometer piece of ground. Successional pathway diagrams must be critically scrutinized and tested for inconsistencies and accuracy. Disturbance probabilities should be validated with actual data and predicted disturbances should be compared with known and recorded activities.

Conclusions

The CRBSUM simulation model is a useful tool for predicting and comparing general shifts in vegetation cover and structure on a coarse-scale landscape as a consequence of alternative land management policies. However, model results are only applicable at the scale at which the input layer and parameters were developed. CRBSUM can be used at many spatial scales as long as the parameters are refined to reflect successional dynamics at the scale of development. Data layers generated by CRBSUM should not be used at finer spatial scales because of the stochastic nature of disturbance simulation.

CRBSUM is robust with application to many biomes, time scales, and geographic areas. Ideally, CRBSUM could be used to investigate vegetation dynamics on any size landscape in any region of the world. All that is needed are quantified successional pathway diagrams for appropriate potential vegetation types and maps that portray the spatial distributions of PVT, cover type, and structural stage. The accuracy of CRBSUM results depends on the quality of the model input parameters. Comprehensive testing and validation of input parameters can be done with the VDDT computer program. Future versions of CRBSUM will

rectify many conceptual and computational limitations with model design. This involves linking contagion with disturbance processes, including more complex probability distributions, and improving results presentation and format.

Application of CRBSUM to the Interior Columbia River Basin analysis area for the four management futures was quite successful. Output generated by CRBSUM should be worthwhile for completion of the environmental impact statement for the entire basin because predicted trends seem reasonable, output is germane to most resource management concerns, and results have an apparently acceptable range of variation (1 to 3 percent). The level of detail implemented into the coarse-scale CRBSUM application seems to match the level of analysis needed by Interior Columbia River Basin scientific assessment and specified in model objectives (see "Introduction" section). Results and products generated from CRBSUM are being used by other analysis teams and cooperators involved in the Interior Columbia River Basin scientific assessment effort, such as the groups concerned with wildlife, aquatics, and hydrologic issues. A new version of CRBSUM called LANDSUM, has been developed to model succession at finer scales using a stand-based approach rather than a pixel-based approach.

Glossary

ASCII File—A digital data file stored on a computer in ASCII (American Standard Coding for Informational Interchange) format.

Cover Type—A vegetation classification depicting the major tree, shrub, or grass species having the plurality of canopy cover.

Data Layer—A thematic raster layer describing a section of ground.

Disturbance—A perturbation that affects the condition of a succession class by altering cover type, structural stage, or succession age.

Landunit—A combination of PVT and succession class that defines a unit of land. This is used as a stratification in the Scenario File.

Loki—A computer software package that controls the execution and scheduling of various models and allows the query and modification of digital maps.

Management Action—A human-caused or natural perturbation or disturbance that a pixel can experience in a simulation year.

Management Future—A modeling scenario meant to describe an extreme but acceptable land management policy.

Management Region—A subjective delineation of a land area map based on defined management or ecological objectives.

Phase—A finite length of time in which a management scenario applies.

Pixel—A square section of a raster map of varying resolution.

Potential Vegetation Type (PVT)—An abstract representation of the biophysical properties of a section of land that is described by the successional convergence to a homogeneous vegetation community. Coarse-scale PVT's are usually a group of similar habitat types or plant associations.

Raster Map—An electronic map that is divided into a grid with the gridded divisions (square pieces) called pixels. Also called a data layer.

Scenario File—An ASCII computer file that contains all disturbance probability parameters stratified by phase, management region, PVT, and landunit that describe a management scenario.

Succession Age—An index of successional development measured in years.

Succession Class—A stage of successional development described by a cover type and structural stage. This is roughly equivalent to a seral community type described by species composition and community structure.

Succession File—An ASCII computer file that contains all parameters that describe a successional pathway.

Successional Pathway—A sequence of succession classes that terminate in a stable succession class that describes the PVT.

Structural Stage—A stage of development of a vegetation stand based on the level of competition experienced by individuals that comprise the stand.

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Appendix A: Potential Vegetation Types Used in the Interior Columbia River Basin Scientific Assessment for Forest and Rangeland Ecosystems

For Forests

PVT ID	Code	Description of Potential Vegetation Types
50	CDHME	Western Redcedar/Hemlock—East
51	CDHMI	Western Redcedar/Hemlock—Inland
52	DRDFA	Dry Douglas-fir without Ponderosa Pine
53	DRDFB	Dry Douglas-fir with Ponderosa Pine
54	DGFWF	Dry Grand Fir
55	LIMP	Limber Pine
56	LPPA	Lodgepole Pine—Yellowstone
57	LPPB	Lodgepole Pine—Oregon
58	MSDF	Moist Douglas-fir
59	GFWFE	Moist Grand Fir/White Fir—East
60	GFWFI	Moist Grand Fir—Inland
61	MTHME	Mountain Hemlock—East
62	MTHMI	Mountain Hemlock—Inland
63	INTPP	Interior Ponderosa Pine
64	PPSMC	Pacific Pine/Sierra Mixed Conifer
65	MHSRF	Mountain Hemlock/Shasta Red Fir
66	PSLFR	Pacific Silver Fir
67	SFDWA	Spruce/Subalpine Fir—Dry with Aspen
68	SFDNA	Spruce/Subalpine Fir—Dry without Aspen
69	SFWET	Spruce/Subalpine Fir—Wet
70	SFWBP	Spruce/Fir Harsh—Whitebark > Lodgepole
71	SFLPP	Spruce/Fir Harsh—Lodgepole > Whitebark
72	WBALN	Whitebark Pine/Alpine Larch—North
73	WBALS	Whitebark Pine/Alpine Larch—South
74	WHTOK	Oregon White Oak

For Range

PVT	File	Description of Potential Vegetation Types
101	AGST	Agropyron Steppe
102	PUTR	*Purshia Tridentata*
103	BSBW	Basin Big Sage/Wildrye
104	LSME	Low Sage—Mesic
105	LSMJ	Low Sage—Mesic with Juniper
106	LSXE	Low Sage—Xeric
107	LSXJ	Low Sage—Xeric with Juniper
108	WBSW	Wyoming Big Sage—Warm
109	WBSC	Wyoming Big Sage—Cool
110	CTRV	Cottonwood Riverine
111	FESC	Fescue Grassland
112	BSML	Mountain Big Sage—Mesic—East
113	BSMC	Mountain Big Sage—Mesic—East—Conifer
114	BSMW	Mountain Big Sage—Mesic—West
115	BSMJ	Mountain Big Sage Mesic West with Juniper
117	SDSH	Salt Desert Shrub
118	TTSA	Three Tip Sage
119	SALX	*Salix/Carex*
120	ASPEN	Aspen
121	CEW1	Mountain Mahogany Woodland without Sage
122	CEW2	Mountain Mahogany Woodland with Sage
123	MTSH	Mountain Shrub
124	RIGR	Riparian Graminoid
125	SARP	Saltbrush Riparian
126	RPSED	Riparian Sedge
127	MRLS	Mountain Riparian Low Shrub
129	CFESC	Conifer-Fescue Grassland
130	JUOC	Juniper
131	ALSHR	Alpine Shrub—Herbaceous

Appendix B: Cover Types Used in the Interior Columbia River Basin Scientific Assessment

Cover Types

No.	Code	Name	Description
1001	CRB006	Rock	Rock/Barrenlands
1002	CRBS20	Water	Water
1004	CRB003	GrFrb	Grass/Forb
1005	CRB003	ShReg	Shrub/Regen
1009	CRB009	Exoti	Exotic
1010	SRM304	PeNbu	Perennial Native Bunchgrass
1013	CRB003	MtShr	Mountain Shrub No Other
1015	CRB003	MoShr	General Shrub
1016	CRB003	MtShc	Mountain Shrub Ceanothus
2001	SAF206	SpSaf	Spruce/Subalpine Fir
2002	SAF208	WBP	Whitebark Pine
2003	SAF210	DF	Douglas-fir
2005	SAF212	WL	Western Larch
2006	CRBS09	GWF	Grand/White Fir
2007	SAF215	WP	White Pine
2008	SAF217	Aspen	Aspen
2009	SAF218	LPP	Lodgepole Pine
2010	SAF205	MtH	Mountain Hemlock
2011	CRB008	PSF	Pacific Silver Fir
2012	SAF227	HmCed	Hemlock/Cedar
2013	CRBS11	SRF	Shasta Red Fir
2018	SAF237	IPP	Interior Ponderosa Pine
2023	CRBS10	WbpAl	White Bark Pine/Subalpine Larch
2024	CRBS10	SaL	Subalpine Larch
2025	CRBS02	JuWsi	Juniper Woodland
2027	SAF219	LBP	Limber Pine
2030	SAF243	SMC	Sierra Mixed Conifer
2031	SAF245	PPP	Pacific Ponderosa Pine
3001	SRM101	AgSpi	*Agropyron spicatum* (AGSP)
3003	SRM104	PuAgr	*Purshia/Agropyron spicatum*
3004	CRBS03	JuSwg	Juniper Sagebrush Wheatgrass
3007	SRM322	MtMah	Mountain Mahogany
3010	SRM304	IfWhg	Idaho Fescue Wheatgrass
3013	SRM403	ArWyo	*Artemisia tridentata tridentata*
3015	SRM414	SaDsh	Salt Desert Shrub
3016	SRM421	ChSer	Chokecherry Serviceberry Rose
3021	SRM401	ArTrn	*Artemisia tridentata tridentata*/Wild rye
3022	SRM403	ArTrp	Three tip Sagebrush
4001	CRB013	CoEeg	Conifer Encroachment Exotic Grass
4003	CRBS08	ExFor	Exotic Forbs
4013	SRM304	SeNag	Seeded Native Grass (AGSP/FEID)
4015	SRM304	LoPgr	Low productivity Perennial Grass
4019	CRBS07	PiFor	Pioneer Forbs
4020	SRM304	SmPgr	Small Perennial Grass
4021	CRBS07	NaFor	Native Forbs
4022	CRBS08	ExPgr	Exotic Perennial Grass
4023	CRBS08	ExFor	Exotic Forbs
4024	CRBS08	ExHer	Exotic Herbaceous
4025	CRBS01	JuExh	Juniper Forest/Exotic Herb
4027	SRM406	ArAbh	*Artemisia arbuscula* Native Forbs
4028	CRBS01	JuLsg	Juniper Lowsage Shortgrass
4029	CRBS01	JuPos	Juniper/*Poa secunda*
4031	SRM406	ArAbg	*Artemisia arbuscula* Native Bunchgrass
4038	CRBS06	ExGra	Exotic Annual Grass
4040	CRBS06	SiHys	*Sitanion hystrix*
4042	CRBS06	PoSec	*Poa secunda*
4047	CRBS08	ExGra	Exotic Grass
4048	SRM304	SeNag	Seeded Native Grass
4049	SRM101	FiGra	Fire Maintained Grass
4057	CRBS06	PoPra	*Poa pratensis*
4058	CRBS05	SaCar	*Salix* Low Carex
4059	CRBS05	SaGra	*Salix* Low Grass

(con.)

Cover Types

No.	Code	Name	Description
4060	CRB007	GrCar	Grass *Carex*
4079	CRBS05	GrBar	Gravel
4080	SAF235	PoCor	*Populus/Cornus* cottonwood Dogwood
4081	SAF235	PoTri	*Populus*
4084	SAF235	PoPoa	*Populus/Poa pratensis* cottonwood Bluegrass
4087	CRBS05	CoCra	*Cornus Crateagus* Riparian Shrub
4089	CRBS05	SaCal	*Salix/Calamagrostis*
4090	CRBS05	SaCbe	*Salix/Carex* Beaver
4092	CRBS05	SaPoa	*Salix/Poa pratensis*
4093	CRBS08	ExHer	Exotic Herbs
4094	CRBS07	DeCal	*Deschampsia/Calamagrostis*
4095	CRBS07	ExRhe	Exotic Riparian Herbs
4096	CRBS07	ExMhe	Exotic Moist Herbs
4097	SRM101	AgPse	*Agropyron/Poa secunda*
4098	CRBS06	PsFoc	*Poa Secunda/Festuca octaflora*
4099	SRM406	ArPse	*Artemisia/Poa secunda*
5001	CRBS06	BrTec	*Bromus tectorum*
5002	SRM403	ArBte	*Artemisia/Bromus tectorum*
5006	SRM614	SeEag	Seeded Exotic Agropyron
5009	SRM402	ArVtp	*Artemisia vaseyana, tridentata*, Perennial Grass
5011	CRBS02	CoSgr	Conifer encroachment Sage Perennial Grass
5012	SRM101	NaPgr	Native Perennial Grass
5013	SRM402	ArVth	*Artemisia vaseyana, tridentata*, Perrennial Herbs
5014	SRM304	PnAhe	Perennial Native Herbaceous
5016	SRM402	ArVtp	*Artemisia vaseyana, tridentata*, Perennial Grass
5017	CRBS02	CoSgr	Conifer encroachment Sage Perennial Grass
5019	CRBS02	CoPgr	Conifer Perennial Grass
5021	SRM402	ArVth	*Artemisia vaseyana, tridentata*, Exotic Herbs
5039	CRBS15	IrCro	Irrigated Crop
5040	CRBS18	DrPah	Dryland Pasture/Hay Land
5041	CRBS17	IrPah	Irrigated Pasture/Hay Land
5043	CRBS19	Urban	Urban Land
5046	CRBS16	DrCro	Dryland Crop
5047	CRBS18	DrPah	Dryland Pasture/Hay Land
5050	SRM401	ElCin	*Elymus cinereus*
5051	SRM101	ElCag	*Elymus cinereus/Agropyron*
5052	SRM401	ElCbt	*Elymus cinereus/Bromus tectorum*
5053	SRM614	AgCrj	*Agropyron cristatum*
5055	SRM614	AgCbt	*Agropyron cristatum/Bromus tectorum*
5056	SRM101	PeHer	Perennial Herbs
5059	SRM403	ArTpe	*Artemisia triparteta*/Exotic
5060	SRM403	ArTpa	*Artemisia triparteta/Agropyron cristatum*
5061	SRM406	ArLon	*Aristida longiseta*
5062	SRM406	ArAbt	*Artemisia arbuscula/Bromus tectorum*
5063	SRM607	PuBte	*Purshia tridentata/Bromus tectorum*
5064	CRBS06	PoSpf	*Poa secunda*/Perennial Forbs
5066	CRBS05	SaVer	*Sarcobatus vermiculatus*
5067	CRB007	RyGra	Ryegrass
5068	SRM414	GrSgr	Greasewood, saltgrass
5069	SRM414	GrWoo	Greasewood
5070	SRM107	JuAff	Juniper, Forb
5072	CBB005	PhLsh	Phylodoce Low Shrub
5073	CRBS02	CoEhe	Conifer Exotic Herbs
5074	CRBS01	JuNbu	Juniper Native Bunchgrass
5075	CRBS01	JuUeh	Juniper ui Exotic Herbs
5076	SAF237	PiPsh	*Pinus, Populus*, Shrub
5077	SAF210	PsAps	Douglas-fir, Grand fir, Populus, Shrub
5078	SAF237	PiPex	*Pinus, Populus*, Exotic
5079	SAF210	PsAex	Douglas-fir, Grand fir, Exotic
5080	SAF233	WoShr	White Oak Shrub
5081	CRB003	WoMsw	Mid Shrub
5082	SAF233	WoExo	White Oak, Exotic
5084	CRB007	CaRos	*Carex rostrata/Carex aqualilis*
5085	CRB007	CaNeb	*Carex nebraskensis*

Appendix C: Structural Stages Used in Interior Columbia River Basin Scientific Assessment

Stage ID	Code	Description
Forest	*Structural*	*Stages*
1	SI_F	Stand initiation
2	SEO_F	Stem exclusion—open canopy
3	SEC_F	Stem exclusion—closed canopy
4	UR_F	Understory reinitiation
5	YMS_F	Young forest—multistrata
6	OMS_F	Old forest—multistrata
7	OSS_F	Old forest—single strata
Woodland	*Structural*	*Stages*
11	SI_W	Stand initiation
12	SEC_W	Stem exclusion—closed canopy
13	UR_W	
14	YMS_W	Young multi-strata
15	OMS_W	Old multi-strata
16	OSS_W	Old single strata
Rangeland	*Structural*	*Stages*
21	OHERB	Open herbland
22	CHERB	Closed herbland
23	OLSHR	Open, low shrubland
24	CLSHR	Closed, low shrubland
25	OMSHR	Open, mid-sized shrubland
26	CMSHR	Closed, mid-sized shrubland
27	OTSHR	Open, tall shrubland
28	CTSHR	Closed, tall shrubland

Appendix D: Disturbances Used in the Interior Columbia River Basin Scientific Assessment

Note: Numbers following repeat disturbance actions (such as #1) denote a different severity of disturbance within the same pathway. For example, a Dry DF PVT pathway may have several partial cuts within the pathway diagrams, and each partial cut may incur a different successional effect.

1001 Clearcut—no site preparation
1003 Group selection cut
1005 Individual selection cut
1006 Overstory removal
1009 Sanitation cut
1012 Shelterwood cut
1014 Clearcut—plant ponderosa pine
1015 Clearcut—plant Douglas-fir
1016 Clearcut—plant western larch
1017 Clearcut—plant lodgepole
1018 Clearcut—plant white pine
1020 Partial cut #6
1021 Partial cut #1
1022 Clearcut and burn
1023 Clearcut and sprout
1027 Partial cut #7
1028 Partial cut #2
1029 Overstory removal #1
1031 Clearcut—no site preparation #2
1035 Partial cut #3
1036 Partial cut #4
1037 Partial cut #5
1040 Shelterwood cut and burn
1041 Shelterwood reserve
1042 Shelterwood reserve #2
1043 Shelterwood reserve #3
1045 Group selection cut #2
1048 Shelterwood dead reserve
1050 Shelterwood dead reserve #2
1052 Clearcut reserve #1
1053 Clearcut reserve #2
1055 Clearcut dead reserve
1101 Commercial thin
1102 Precommercial thin
1103 Thin from below
1104 Thin from above
1105 Thin #2
1106 Thin #3
1108 Thin low #2
1201 Bare root planting
1301 Grazing general
1302 Successional change cattle grazing
1303 Successional maintenance cattle grazing
1304 Successional accelerating cattle grazing
1305 Not grazed by cattle
1306 Successional change big game grazing
1307 Successional maintenance big game grazing
1308 Successional accelerating big game grazing
1309 Not grazed by big game
1310 Successional change cattle grazing and exotics
1311 Successional accel. big game grazing and exotics
1313 Herb. application and seeding native plants
1314 Mechanical preparation and seeding
1315 Winter grazing
1317 Erosion
1318 Unspecified agriculture
1319 Grazing
1320 Successional change sheep grazing
1331 Unspecified seeding
1332 Vegetation manipulation
1333 Vegetation manipulation and unspecified seeding
1334 Vegetation planting i.e. willows
1335 Herbicide applications and exotic seed source
1501 Till, seed annuals, spray
1502 Till, seed
1503 Irrigation
1504 Unspecified development
1505 Till, seed native, spray
1506 Till, seed perennial, spray
2001 Douglas-fir beetle
2002 Mountain pine beetle
2003 Western pine beetle
2004 Mountain pine beetle and western pine beetle
2005 Western pine beetle and stand replacing fire #1
2006 Bark beetles
2007 Spruce beetles
2008 Balsam wooly adelgid
2009 Spruce budworm
2010 Tussock moth
2013 Western pine beetle and root disease
2014 Unspecified defoliators
2016 Douglas-fir beetles and defoliators
2017 Mountain pine beetle #1
2018 Mountain pine beetle #2
2020 Unspecified insects
2021 Bark beetles #2
2022 Less insects and disease than naturally would occur
2023 Douglas-fir beetle #2
2024 Mountain pine beetle #3
2025 Mountain pine beetle #4
2026 Poplar borer
2032 Low intensity bark beetles
2033 High intensity bark beetles
2035 Western pine beetle
2038 Bark beetles #3
2044 Bark beetles #5
2101 Blister rust #1
2102 Dwarf mistletoe
2103 Root disease
2104 Canker
2106 Stem decay
2111 Blister rust #2
2112 Root disease #2
2113 Blister rust #3
2114 Leaf disease
2115 Canker #2
2116 Root pathogens
2118 Root disease #3
2119 Root disease and bark beetles
2120 Root disease conversion to Douglas-fir
2121 Severe root disease
2122 Root disease conversion to grand fir
2123 Low intensity root disease
2124 Blister rust #4
2125 Blister rust #5
2126 Blister rust #6
2127 Root disease #3
2128 Root disease #4
2129 Root disease #5
2130 Root disease #6
2133 Aspen diseases
2201 Natural seeding #1

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2202 Natural seeding #2
2203 Natural seeding #3
2204 Natural seeding #4
2205 Natural seeding #5
2206 Natural seeding #6
3001 Wildfire—stand replacing fire
3002 Wildfire—stand replacing fire #2
3003 Wildfire—stand replacing fire #3
3004 Wildfire—mixed severity fire
3005 Wildfire—mixed severity fire #1
3006 Wildfire—mixed severity fire #2
3007 Wildfire—mixed severity fire #3
3008 Wildfire—mixed severity fire #4
3009 Wildfire—underburn
3011 Prescribed—planned stand replacing fire
3012 Prescribed—planned stand replacing fire #2
3013 Prescribed—planned stand replacing fire #3
3014 Prescribed—planned mixed severity fire
3015 Prescribed—planned mixed severity fire #1
3016 Prescribed—planned mixed severity fire #2
3017 Prescribed—planned mixed severity fire #3
3018 Prescribed—planned mixed severity fire #4
3019 Prescribed—planned underburn
3020 Prescribed—planned underburn #2
3021 Prescribed—unplanned stand replacing fire
3022 Prescribed—unplanned stand replacing fire
3023 Prescribed—unplanned stand replacing fire
3024 Prescribed—unplanned mixed severity fire
3025 Prescribed—unplanned mixed severity fire #1
3026 Prescribed—unplanned mixed severity fire #2
3027 Prescribed—unplanned mixed severity fire #3
3028 Prescribed—unplanned mixed severity fire #4
3029 Prescribed—unplanned underburn
3030 Wildfire control
3032 Prescribed—planned mixed severity fire #5
3033 Prescribed—unplanned mixed severity fire #5
3034 Non-lethal wildfire
3035 Prescribed—planned non-lethal fire
3036 Prescribed—unplanned non-lethal fire
3102 Drought damage
3106 Snow breakage
3207 Rodents
3208 Beaver
3306 Exotic grass
3401 Successional change cattle grazing and exotic grass
3402 Successional change cattle grazing and exotic forbs
3403 Successional change big game grazing and exotic grass
3404 Successional change big game grazing and exotic forbs
3406 Partial cut and severe wind-throw
3416 Successional change cattle grazing and exotics
3417 Successional change cattle grazing and exotics
3418 Insects and disease combination #1
3419 Insects and disease combination #2
3420 Insects and disease combination #3
3421 Insects and disease combination #4
3422 Insects and disease combination #5
3423 Insects and disease combination #6
3424 Insects and disease combination #7
3425 Dwarf mistletoe
3426 Insects and disease combination #8
3428 Clearcut and successional change cattle grazing
3429 Clearcut and successional change big game grazing
3430 Underburn and thin
3440 Root disease and wild underburn
3441 Root disease and prescribed-planned underburn
3442 Root disease and prescribed-unplanned underburn
3446 Wildfire—stand replacing fire and exotic grass
3447 Prescribed—planned stand replacement fire and exotic grass
3448 Prescribed—unplanned stand replacement fire and exotic grass
3465 Wildfire—stand-replacement and successional change cattle grazing
3466 Prescribed—planned stand-replacement and successional change cattle grazing
3467 Prescribed—unplanned stand-replacement and successional change cattle grazing
3468 Wildfire—stand-replacement and successional change big game grazing
3469 Prescribed—planned stand-replacement and successional change big game grazing
3470 Prescribed—unplanned stand-replacement and successional change big game grazing
3483 Mixed severity fire and bark beetles
3484 Insect and disease combo and Douglas-fir beetle
3485 Mountain pine beetle
3490 Flood and succession
3491 Water table drop and drought
3492 Water table drop
3493 Decay, bark beetles, and erosion

Appendix E: An Example of the CRBSUM Input Succession File

```
CRBSUM - Columbia River Basin Historical and Current PVT information file
  1  AGST        4                                                 <<<< PVT Info
    223001    22   3001    101     999    223001     0     4      <<<< Succession Class
          1306 BSCG                225061     71          0       <<<< Disturbances
          1309 BSNG                223001    101          1
          1317 Erosion             214019      1          0
          3034 WNonLethal          223001    101          0
    214021     21       4021       51       101      223001       0        5
          1309 BSNG                214021     51          1
          1317 Erosion             214019      1          0
          3034 WNonLethal          214021     51          0
          3035 PPNonLethal         214021     51          0
          3036 PUNonLethal         214021     51          0
    214019     21       4019        1        51      214021       0        1
          3034 WNonLethal          214019      1          0
    225061     22       5061       71       101      223001       0        2
          1307 BSMG                225061     71          0
          1309 BSNG                225061     71          1
  2  PUTR         3
    233003     23       3003      101      1100      233003       0        3
          1306 BSCG                224049     76          0
          1307 BSMG                233003    101          0
          3001 WSRF                224049     76          0
    224049     22       4049       76       177      233003       0        4
          1306 BSCG                214049     51          0
          1307 BSMG                224049     76          0
          1308 BSAG                233003    101          0
          3001 WSRF                224049     76          0
    214049     21       4049       51        76      224049       0        2
          1307 BSMG                214049     51          0
          3001 WSRF                214049     51          0
 3  BSBW         4
    233021     23       3021       51      1050      233021       0        2
          1306 BSCG                235051     21         20
          3001 WSRF                225050     31         10
    235051     23       5051        1      1000      235051       0        2
          1306 BSCG                225050     21          0
          3001 WSRF                214040      1          0
    225050     22       5050       21        72      233021       0        3
          1308 BSAG                233021     61         10
          1315 WinterGraze         225050     21          0
          3001 WSRF                225050     21          0
    214040     21       4040        1        22      225050       0        2
          1306 BSCG                235051     21         20
          3001 WSRF                214040      1          0
4  LSME         6
    225012     22       5012       51        56      234031       0        3
          1306 BSCG                215064      1          0
          1308 BSAG                234031     56          0
          3001 WSRF                225012     51          0
    234031     23       4031       56        66      244031       0        5
          1306 BSCG                244027      1          0
          1308 BSAG                244031      4          0
          2020 InsectsGen          225012     51          0
          3001 WSRF                225012     51          0
          3207 Rodents             225012     51          0
    244031     24       4031        4        29      225012       0        4
          1306 BSCG                234027      1          0
          2020 InsectsGen          225012     51          0
          3001 WSRF                225012     51          0
          3207 Rodents             225012     51          0
```

Appendix F: An Example of the CRBSUM Input Scenario File

```
CRBSUM -- Consumptive Demand Scenario File: Entire Basin
    1    PhaseOne        0        300           18            <<<<<<< Phase
         1      BLM-Lands-Wilderness             691            <<<<<<< Management Region
           50     Cedar-Hemlock-PVT          12007          4    <<<<<<< LandUnit
             2101      Blister-Rust1          0.015000          <<<<<<< Management Actions
             2111      Blister-Rust2          0.007000
             2113      Blister-Rust3          0.030000
             3001      WSRF      0.006030
           50     CDHME        32007          7
             2101      Blister-Rust1          0.004000
             2111      Blister-Rust2          0.001000
             2113      Blister-Rust3          0.005500
             2124      BR4       0.002000
             3001      WSRF      0.001000
             3005      WMSF1     0.000560
             3006      WMSF2     0.001200
           50     CDHME        42007          8
             2101      Blister-Rust1          0.004000
             2111      Blister-Rust2          0.003000
             2113      Blister-Rust3          0.003000
             3001      WSRF      0.004500
             3005      WMSF1     0.002500
             3006      WMSF2     0.003500
             3007      WMFS3     0.001000
             3008      WMSF4     0.003000
           50     CDHME        62007          7
             2101      Blister-Rust1          0.009000
             3001      WSRF      0.009000
             3004      WMSF      0.001200
             3005      WMSF1     0.000400
             3006      WMSF2     0.001000
             3007      WMFS3     0.001400
             3419      RR2       0.005000
```

Appendix G: An Example of the CRBSUM Simulation File

```
CRBSUM -- Here are the general simulation input parameters
        10  Number of years to simulate succession
      1995  Starting year date of simulation
    1000.0  Width or size of pixel in meters
         1  Scale at which model is operating (1-coarse, 2-mid, 3-fine)
         1  Number of time frames (phases) for scenario implementation
        18  Number of regions to stratify scenario implementation spatially
        85  Number of Potential vegetation types in this application
        45  Number of LCC categories
         2  Initialize option (1-from elu/lcc data, 2-lcc/stage dist,3-stage map, 4-random)
         4  Age initialization option (1-Random, 2-midpoint of stage, 3-entered beg age, 4-map)
         4  Output results (0-none, 1-short sum, 2-action sum, 3-full sum, 4-full sum,no tabs)
        10  Interval (yrs) to print results to output tabular files
         1  Harvest output specifics (1-NO output, 2-Harvest by volumes, 3-Harvest by trantime)
        40  Number of map attributes to assess for each map (multiples of 10, max of 100)
Enter below the Disturbance ID numbers you want mapped by map category
FireMap1           3001 3004 3009 3011 3014 3019 3021 3024 3029 0000 <<<<< Fire Disturbance IDs to map
FireMap2           0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
FireMap3           0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
FireMap4           0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
InsectDiseaseMap1  0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 <<<<< Insect/disease Disturbances to map
InsectDiseaseMap2  0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
InsectDiseaseMap3  0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
InsectDiseaseMap4  0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
HarvestMap1        1001 1014 1002 1003 1004 1005 1006 1007 1008 1009 <<<<< Timber Harvest Disturbances to map
HarvestMap2        1100 1101 1102 1103 1104 1105 1106 1107 1108 1109
HarvestMap3        1021 1022 1023 1024 1025 1026 1027 1028 1029 1030
HarvestMap4        0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
GrazingMap1        1301 1302 1303 1304 1305 0000 0000 0000 0000 0000 <<<<< Grazing Disturbances to map
GrazingMap2        0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
GrazingMap3        0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
GrazingMap4        0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
DisturbanceMap1    0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 <<<<< User-specified Disturbances to map
DisturbanceMap2    0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
DisturbanceMap3    0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
DisturbanceMap4    0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
```

Appendix H: An Example of the Driver File for CRBSUM

```
CRBSUM: Consumptive Demand Management Future File Specificiations
/data25g/crb/outfiles/cd/echo.out            This is the output file name for echo of model input
/data25g/crb/outfiles/cd/error.out           This is the output file name for error messages
/data25g/crb/infiles/crb.sim                 This is the input file for simulation specifics
/data25g/crb/infiles/crb.pvt                 File containing info on struct stage by elu
/data25g/crb/infiles/crb.lcc                 File containing info on PVT to lcc crosswalk
/data25g/crb/infiles/crb.scn.cd              File containing info on land management actions
/data25g/crb/infiles/crb.vol                 File containing info on volume equation parameters
/data25g/crb/outfiles/cd/crb.out             File used to store yearly output
/data25g/crb/outfiles/cd/landscape.stat      File to store yearly landscape output for stats program
/data25g/crb/outfiles/cd/action.stat         File to store yearly disturbance output for stats program
/data25g/crb/outfiles/cd/harvest.stat        File to store harvestXtransition times
```

Appendix I: Example of a Structural Stage Initiation File in CRBSUM

```
CRBSUM -- File to initialize structural stage map from cover type/pvt
        1   PonderosaPine   5                 <<<<< Cover type
          1  DryPonderosaPine     7           <<<<< PVT #1
            1 StandInit        2.10           <<<<< Structural stage and proportion
            2 StemExOpen      30.30
            3 StemExClos       0.00
            4 UnderReinit      0.00
            5 YFMS             0.00
            6 OFMS            17.10
            7 OFSS            50.50
          9  DryDouglasFir        7          <<<<< PVT  #2
            1 StandInit        9.00
            2 StemExOpen      56.60
            3 StemExClos       0.00
            4 UnderReinit      0.00
            5 YFMS             0.00
            6 OFMS             8.60
            7 OFSS            25.80
         8  GrandFir              7          <<<<< PVT  #3
            1 StandInit       34.00
            2 StemExOpen      59.40
            3 StemExClos       0.00
            4 UnderReinit      0.00
            5 YFMS             0.00
            6 OFMS             0.00
            7 OFSS             6.60
         11  MoistPonderosaPine  7           <<<<< PVT  #4
            1 StandInit        7.40
            2 StemExOpen      34.40
            3 StemExClos       0.00
            4 UnderReinit      0.00
            5 YFMS             0.00
            6 OFMS            29.10
            7 OFSS            29.10
         25  Cedar/Hemlock       7           <<<<< PVT  #5
            1 StandInit        7.90
            2 StemExOpen      36.70
            3 StemExClos       0.00
            4 UnderReinit      0.00
            5 YFMS             0.00
            6 OFMS            27.70
            7 OFSS            27.70
```

Appendix J: An Example of the Volume File for CRBSUM

CRBSUM -- Volume Parameters for ICRB simulations - Note: 999.0 indicates no data available

PVT	SC	Action Code	Harv Code	Alpha	Beta	Reduction Factor
105	115070	1001	941	999.0	999.0	999.0
105	132025	1001	942	999.0	999.0	999.0
105	135070	1001	943	999.0	999.0	999.0
105	154025	1001	944	999.0	999.0	999.0
105	165070	1001	945	999.0	999.0	999.0
107	154028	1001	946	999.0	999.0	999.0
110	34081	1023	947	999.0	999.0	999.0
110	34084	1001	948	999.0	999.0	999.0
110	44081	1023	949	999.0	999.0	999.0
110	44084	1001	950	999.0	999.0	999.0
110	45076	1001	951	999.0	999.0	999.0
110	45078	1001	952	999.0	999.0	999.0
110	54081	1005	954	999.0	999.0	999.0
110	54081	1023	953	999.0	999.0	999.0
110	54084	1001	955	999.0	999.0	999.0
110	55077	1001	956	999.0	999.0	999.0
110	55079	1001	957	999.0	999.0	999.0
110	64081	1001	958	999.0	999.0	999.0
110	64084	1001	959	999.0	999.0	999.0
110	65076	1001	960	999.0	999.0	999.0
110	65077	1001	961	999.0	999.0	999.0
110	65078	1001	962	999.0	999.0	999.0
110	65079	1001	963	999.0	999.0	999.0
110	72018	1001	964	999.0	999.0	999.0
110	75078	1001	965	999.0	999.0	999.0

Appendix K: CRBSUM Output File Formats

DATA FILE: LANDSCAPE.STAT

Field	Variable name	Field size	Field type	Field description
1	YEAR	5	Integer	Simulation year
2	MREG	6	Integer	Management region ID
3	PVT	6	Integer	Potential vegetation type ID
4	CLASS	11	Integer	Succession class ID
5	STAGE	11	Integer	Structural stage ID
6	COVER	11	Integer	Cover type ID
7	AREA	11.2	Real	Area of coverage in this type (km^2)

DATA FILE: ACTION.STAT

Field	Variable name	Field size	Field type	Field description
1	YEAR	5	Integer	Simulation year
2	MREG	6	Integer	Management region ID
3	PVT	6	Integer	Potential vegetation type ID
4	CLASS	11	Integer	Succession class ID
5	STAGE	11	Integer	Structural stage ID
6	COVER	11	Integer	Cover type ID
7	ACTION	11	Integer	Management action ID
8	AREA	11.2	Real	Area of coverage in this type (km^2)

DATA FILE: HARVEST.STAT (With Volume Equations)

Field	Variable name	Field size	Field type	Field description
1	YEAR	5	Integer	Simulation year
2	MREG	6	Integer	Management region ID
3	PVT	6	Integer	Potential vegetation type ID
4	CLASS	11	Integer	Succession class ID
5	STAGE	11	Integer	Structural stage ID
6	COVER	11	Integer	Cover type ID
7	HARVEST	11	Integer	Harvest management action ID
8	AREA	11.2	Real	Area of coverage in this type (km^2)
9	VOLUME	11.2	Real	Volume of wood harvested (m^3 ha^{-1})

DATA FILE: HARVEST.STAT (Without Volume Equations)

Field	Variable name	Field size	Field type	Field description
1	YEAR	5	Integer	Simulation year
2	MREG	6	Integer	Management region ID
3	PVT	6	Integer	Potential vegetation type ID
4	CLASS	11	Integer	Succession class ID
5	STAGE	11	Integer	Structural stage ID
6	COVER	11	Integer	Cover type ID
7	HARVEST	11	Integer	Harvest management action ID
8	TRANTIME	11	Integer	Transition time to next class (yrs)
9	AREA	11.2	Real	Area of coverage in this type (km^2)

Appendix L: Management Regions Included in the Interior Columbia River Basin Simulation Effort

1. Eastside EIS Area (eastern Washington and Oregon); BLM/FS[1] Wilderness
2. Eastside EIS Area; BLM/FS Nonwilderness
3. Eastside EIS Area; National Parks
4. Eastside EIS Area; Other State, Federal, City, County
5. Eastside EIS Area; Tribal
6. Eastside EIS Area; Private
7. Upper Columbia River (western Montana, Idaho) EIS Area; BLM/FS Wilderness
8. Upper Columbia River (western Montana, Idaho) EIS Area; BLM/FS Nonwilderness
9. Upper Columbia River (western Montana, Idaho) EIS Area; National Parks
10. Upper Columbia River (western Montana, Idaho) EIS Area; Other State, Federal, City, County
11. Upper Columbia River (western Montana, Idaho) EIS Area; Tribal
12. Upper Columbia River (western Montana, Idaho) EIS Area; Private
13. Outside EIS Areas; BLM/FS Wilderness
14. Outside EIS Areas; BLM/FS Nonwilderness
15. Outside EIS Areas; National Parks
16. Outside EIS Areas; Other State, Federal, City, County
17. Outside EIS Areas; Tribal
18. Outside EIS Areas; Private

[1]BLM—Bureau of Land Manangement Lands, FS—USDA Forest Service Lands.

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Keane, Robert E.; Long, Donald G.; Menakis, James P.; Hann, Wendel J.; Bevins, Collin D. 1996. Simulating coarse-scale vegetation dynamics using the Columbia River Basin Succession Model—CRBSUM. Gen. Tech. Rep. INT-GTR-340. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 50 p.

The Columbia River Basin SUccession Model (CRBSUM) simulates broad-scale landscape changes as a consequence of various land management policies. CRBSUM is a spatially explicit, deterministic model with stochastic properties that simulates changes in vegetation cover types and structural stages on landscapes over long periods. CRBSUM was used to simulate coarse-scale landscape changes in the Interior Columbia River Basin as a result of four management scenarios called management futures. CRBSUM results have an inherent 1 to 5 percent variability because of the stochastic structure of the model. Sensitivity analysis results suggest moderate changes in disturbance probabilities (25 percent increase) will only slightly affect simulated results.

Keywords: succession modeling, stochastic model, Interior Columbia River Basin, succession pathways, GIS, Loki simulation system, computer model

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